GEOLOGY OF THE NINEMILE AREA,

SAN PETE COUNTY, UTAH

A SENIOR THESIS

presented by

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CONTENTS

INTRODUCTION

LOCATION AND EXTENT

The Ninemile Area of Sanpete County, Utah covers about twelve square miles in R.2E., T.19 S. of the Salt Lake Meridian. This area includes sections 5-8, 16-18, 20-21, and parts of sections 4, 9, 15, 19, and 22. It is located one-hundred and twenty-five miles south of Salt Lake City and includes the southeastern part of the Gunnison Plateau, the lower part of the San Pete Valley, and the southwest portion of the Wasatch Plateau.

There are numerous villages and hamlets in the region. These include Sterling on the northeastern edge of the area, Manti, the county seat, five miles to the north, Mayfield one mile from the southern limit, and Gunnison four miles to the southwest. Eleven miles northeast of the Ninemile Area is the village of Ephraim, where Snow College is located. The latter is the base of operations for the field and research work in central Utah of the Geology Department of the Ohio State University. This report is an account of the work done at the field station during the summer of 1970.

GEOGRAPHY

The plateaus and basins of central Utah provide contrasting physical features. The plateaus are important to man for their lumber, grazing lands, hunting, fishing, camping and other forms of recreation, while the valleys with their rich alluvial soil are used for growing alfalfa, hay, barley, sugar beets and other crops.

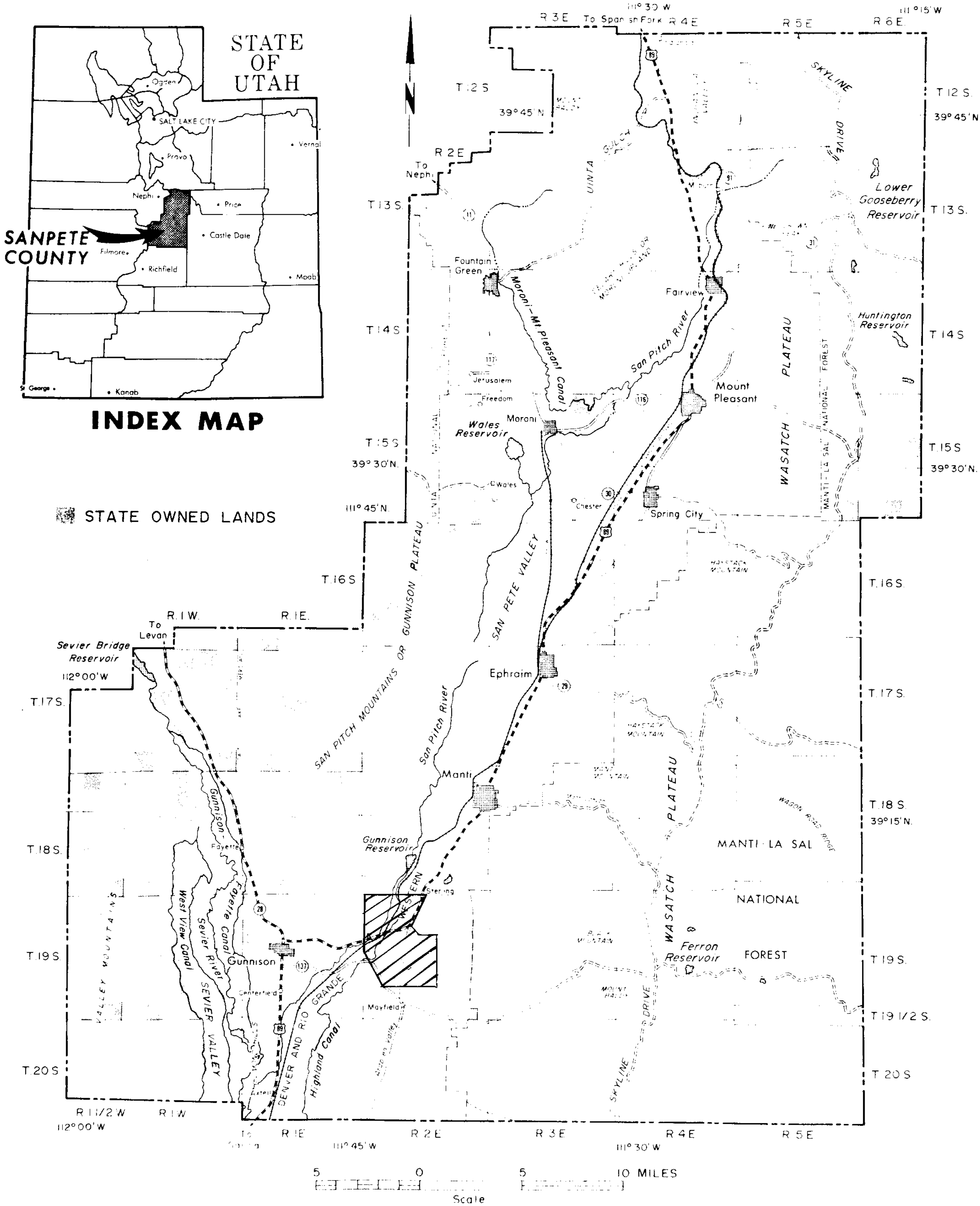

Fig. 1. Index Map

Cross-hatched section indicates the Ninemile area in Sanpete County.

Cattle and sheep ranching has been a consistent agricultural enterprise; in recent years modern dairy and poultry farming have been developed. Furthermore, a processing plant has been built to accommodate the fast-growing turkey business.

Also of interest to man are the mineral resources and fossil fuels. The main commercial minerals are salt and gypsum; petroleum, gas, and coal are found in various amounts.

The climate of the region is semi-arid. The temperature ranges from the mid-90° F in the day and mid-50° F at night in the summer. In the winter the temperature ranges from the mid-10° F in the day and from around 0° F to the mid-10° F at night.

In the basins or valley bottoms the rainfall averages 12 inches or less annually. Average precipitation on the Gunnison Plateau is 25 inches; on the Wasatch Plateau it may be as high as 40 inches per year. Much of the precipitation on the plateaus occurs as snowfall, which may remain on the ground a considerable part of the year. Furthermore, 40 inches of precipitation results in 20 inches of runoff, 25 inches provides 8 inches of runoff, and 12 inches yields little or no runoff. Consequently the frequent summer thunder showers in the valley provide only a small amount of groundwater, since the dry atmosphere causes a high rate of evaporation (Bagley, 1964, p. 55).

Topographically, the lowest elevation in the Ninemile Area is 5243 feet in section 18. On the Gunnison Plateau the highest elevation is 5974 feet, and on the Wasatch Plateau it is 6640 feet. Generally the highest elevations in the region are on the Wasatch Plateau and in the southern Wasatch Mountains. The elevation of Mt. Nebo, the southernmost peak of the Wasatch Range is 11,871 feet, and parts of the Wasatch

Plateau are over 12,000 feet in elevation.

FLORA AND FAUNA

The flora and fauna of Utah and Nevada are distributed in five distinct life zones. These life zones may often overlap. Moreover, they are the response of the plant and animal life to the variations in climate, soil, and elevation. A generalized description of the five zones follows:

a) Upper Sonoran Zone - This zone surrounds the forest. In central Utah it is found in the valley bottoms and foothills of the plateaus. Plant life includes sagebrush, many species of small cacti, juniper and pinyon. Animal life present are prairie rattlers, bull snakes, and other small reptiles, along with numerous jackrabbits and cottontails.

b) Transition Zone - This zone is found in the forest canyons. It provides a habitat for mule deer, bobcats, coyotes, and cougars. Plant life includes mountain mahogany, white fir, and ponderosa pine. This zone in central Utah in intermediate between the valley bottoms and the high plateaus.

c) Canadian Zone - In this zone, forests of Douglas fir and aspen are abundant. Wildlife is plentiful during the summer and in the pioneer era mountain sheep were often seen. In central Utah this zone encompasses the high plateau regions.

d) Hudsonian Zone - In this zone, spruce, timber pine, and bristle cone pine of great age are plentiful. They are often found in grotesque shapes with trunks up to 30 feet in circumference. In central Utah this zone is found only in the uppermost part of the high plateaus.

e) Arctic-Alpine Zone - This zone extends from the timber line to the mountain crests. It abounds in many varieties of moss, lichen, and tundra plants. In central Utah this zone occurs near the crests of peaks, like Mt. Nebo of the Wasatch Mountains.

In central Utah, as in other regions, the near-extinction of some species has had a harmful effect. The slaughter of coyotes has resulted in an increase of the jackrabbit population. These in turn devour the sparse vegetation on the plateau foothills and valleys. The near-extinction of the cougar has resulted in an expanding deer population, which also eat much of the vegetation, and often the hay and grain of the farmer. An increase in the rodent population results when rattlesnakes and other snakes are indiscriminately killed.

PREVIOUS WORK

Although many geologists have worked in central Utah, Edmund M. Spieker has been responsible for much of the detailed work in stratigraphy, structural geology, tectonics, and geologic history of the area. Furthermore, he has guided numerous other aspiring geologists who have made studies in specific localities or specialized areas.

Some of the early geologists who have worked in the area are G. K. Gilbert, C. E. Dutton, and E. E. Howell.

Others who have contributed to the geology of the area are M. P. Billings, C. E. Hunt, W. N. Gilliland, A. J. Eardley, S. L. Schoff, W. L. Stokes, A. Baker, C. H. Dane, J. B. Reeside, A. LaRocque, and C. H. Summerson.

In the Ninemile Area, Clyde T. Hardy and Julius Babisak have done detailed mapping and evaluation of the geologic structure and stratigraphy.

Over the past 25 years numerous undergraduates have done summer field work in small, well-defined areas in San Pete County.

ACKNOWLEDGEMENTS

In compiling the field data for this report gratitude is expressed for the assistance of Dr. James W. Collinson, Dr. Charles Corbató, and Walter Hasenmueller of the Geology Department of the Ohio State University.

Appreciation is also extended to the staff of Northern Illinois University and Dr. Richard Threet of San Diego State University.

I am further indebted to Dr. Aurèle LaRocque, who guided the writing of this report. Dr. Sidney White and Dr. J. W. Collinson, supplied source materials helpful in organizing the report.

Finally, I acknowledge the help of my associates in the field Dennis Zlatkin and Charles Kuntz, who contributed in mapping the geology of the area.

STRATIGRAPHY

GENERAL STATEMENT

In the Ninemile Area there are ten major stratigraphic units exposed. These formations are:

Name	Age
Axtell Formation	Late Pliocene and Early Pleistocene
Crazy Hollow Formation	Eocene, Late Eocene?
Green River Formation	Eocene, Medial Eocene?
Colton Formation	Eocene and Paleocene, Early Eocene-Late Paleocene
Flagstaff Limestone	Eocene and Paleocene, Early Eocene-Late Paleocene
North Horn Formation	Paleocene-Upper Cretaceous (Lance)
San Pete Formation	Upper Cretaceous, Early Colorado
Morrison (?) Formation	Jurassic?, Upper Jurassic?
Twist Gulch Formation	Jurassic, Upper Jurassic
Arapien Shale	Jurassic, Upper Jurassic, Middle Jurassic

Along with these formations, there is also differentiated a Quaternary stream terrace deposit (Sec. 5 of the map area). Further, the Quaternary alluvial deposits were differentiated into an older deposit on the valley floor and the more recent alluvium that is being transported into the valleys by the ephemeral canyon streams.

The alluvial deposits in the San Pete Valley and Upper Arapien

Valley posed a problem in unravelling the stratigraphy and structure. Our trips to the other areas, notably Snow Canyon, Sixmile Canyon, and Gunnison areas were of great value in clarifying some of these problems.

JURASSIC SYSTEM

Arapien Shale

Definition. This formation was named and defined by Edmund M. Spieker (1946, pp. 123, 124) as a body of red to gray shale and fine-grained sandstone, salt and gypsum-bearing in part. This formation was previously called Jurassic shale by E. E. Howell (1875, pp. 175, 236), C. E. Dutton (1880, pp. 153-154, 163-165), G. B. Richardson (1907, pp. 8-9) and A. J. Eardley (1933, pp. 330-334).

The name of the formation is taken from the Arapien Valley (named after Chief Arapien, a Ute chieftain), which lies north and south of Mayfield, Utah. The type locality is six miles southeast of Gunnison, Utah on the west side of the Wasatch Plateau. (Spieker, 1946, p. 124)

The Arapien Shale was originally divided by Spieker into the Twelve Mile Canyon Member and the Twist Gulch Member. In 1949, C. T. Hardy's exhaustive study of the Arapien Shale resulted in the Twist Gulch Member being redesignated as a formation because of its wide areal extent in Central Utah. (Hardy, 1949, p. 14)

Description. Formerly, the five basic lithologic units of the Arapien Shale according to Spieker were:

Twelve Mile Member

"Type 1. Gray limestone, generally thin-bedded (oldest).

Type 2. Light-gray siltstone and shale, very thin-bedded with occasional thin beds of finely rippled sandstone.

Type 3. Gray shale, argillaceous and gypsiferous with irregular red blotches which locally become dominant.

Type 4. Compact red salt-bearing shale (youngest).

Twist Gulch Member

Type 5. Thin-bedded red siltstone and shale, with layers of greenish-white siltstone and occasional zones of gray sandstone some of which is fairly coarse-grained."

The lower units are dominantly gray and the upper units are mostly red. (Spieker, 1946, p. 124)

The Arapien Shale of the Ninemile Area appears to be composed of Types 2 and 3. The blotched red unit is noticeable on the south side of Highway 89 at the lower end of the Ninemile Reservoir. The gray shale and sandstone unit forms the prominent hogback on the north side of the highway, also near the reservoir.

In 1949, C. T. Hardy's detailed analysis and study of the Arapien Shale revealed this stratigraphic succession:

"Unit A (Spieker's type 1): Gray shale, gray thin-bedded limestone that weathers brown, red shale, gypsum in thin lenticular beds; or gray thin-bedded argillaceous limestone with massive lenticular beds of gypsum.

Unit B (Spieker's type 3): Bluish-gray and red gypsiferous shale. Blotched appearance. Red gypsiferous shale in upper part locally salt-bearing.

Unit C (Spieker's type 2): Bluish-gray calcareous shale with gray thin-bedded calcareous sandstone. Several prominent resistant layers of arenaceous limestone with fossils. Massive lenticular beds of gypsum.

Unit D (Spieker's type 3): Alternate layers of bluish-gray and red gypsiferous shale. Blotched appearance of the outcrop due to lenticular nature of the beds, facies changes, and complex structure.

Unit E (Spieker's type 4): Brick-red silty shale locally salt-bearing. The salt appears to be stratified and commonly contains a considerable amount of red clay. At least 200 feet of salt is exposed east and north of Redmond in the Sevier Valley." (Hardy, 1949, pp. 15, 16)

In the Ninemile Area there are good exposures of the Arapien Shale on the hogback near the Ninemile Reservoir. However, a section was measured at the thickest part of the exposed formation near the modern dairy farm. (Sec. 18, S.E. $\frac{1}{4}$)

The complex structure of the Arapien Shale made it difficult to measure the section. And there is a possibility that there was repetition or omission of beds due to faulting.

Several marker beds were useful in determining faults and folds. These included the resistant sandstone on the hogback (Sec. 8), the gypsum bed in Sec. 17 and Sec. 20, and the red shale and mudstone bed in Sec. 18.

Ripple marks and cross-bedding in the resistant sandstone beds were useful in determining the overturned beds. The fissile shale bed contained mud and clay galls which indicated that flowage took place during compaction.

Distribution, thickness, and stratigraphic relations. In Central Utah, the Arapien Shale is widely distributed. It occurs in the east and north central part of the Sevier Valley and on the east side of Juab Valley, where it forms the western foothills of the Gunnison Plateau. Further, there are scattered outcrops in the Indianola District. In the San Pete Valley the Arapien Shale is also exposed near Wales Gap on the east side of the Gunnison Plateau. (Spieker, 1946, p. 125; 1949, p. 17)

In the Ninemile Area, the Arapien Shale is a prominent formation. It occurs mostly within the confines of the San Pete Valley, and much of it is covered by alluvium. The most important exposures are found in Secs. 8, 18, 19, and 20 of the map area, where the formation forms the core of a fan-shaped anticline.

The thickness of the Arapien Shale may be more than 7,000 feet. (Spieker, 1946, p. 125) In the Ninemile Area the exposed thickness may be only as much as 2100 feet in comparison.

In a complex locality (Sec. 17 of the map area), the Twist Gulch Formation is exposed against the Arapien Shale, but it is difficult to say whether this is a conformable contact. All other contacts between the Arapien Shale and the Twist Gulch Formation in the Ninemile Area are covered by alluvium.

The Green River Formation overlies much of the Arapien Shale in the Ninemile Area. This contact appears to be a depositional unconformity, a fault contact, or possibly both. Moreover, the Axtell Formation unconformably overlies the Arapien Shale, especially in Sec. 18 of the map area.

The base of the formation is not exposed here, but it is presumed that the Navajo or Nugget Sandstone underlies the Arapien Shale throughout San Pete County. (Spieker, 1949, p. 11)

Age and Correlation. Fossils from rocks of Spieker's type 2 have been assigned by J. B. Reeside, Jr., to an Upper Jurassic Age. They are similar to forms found in the Carmel Formation of the San Rafael Group; and these forms include Pentacrinus asteriscus Meek and Hayden and Trigonia quadrangularis Hall and Whitfield. (Spieker, 1946, p. 125)

In the Ninemile Area a member of the field group found Pentacrinus in the gray shale on the hogback (Sec. 8). Nevertheless, fossils are scarce.

The Arapien Shale is correlated eastward with the Carmel Formation. On the basis of lithology, the lower Arapien Shale is correlated with the Twin Creek Limestone on the north. This lithologic similarity is an increase in the amount of limestone in the Arapien Shale on the north and west side of the Gunnison Plateau, which may indicate a transition between the two formations. However, the Arapien Shale may embody elements both older and younger than the San Rafael and the Twin Creek. (Spieker, 1949, p. 18; Babisak, 1949, p. 25)

Twist Gulch Formation

Definition. The Twist Gulch Formation, formerly the upper member of the Arapien Shale was defined by Spieker (1946, p. 124) as comprising the strata exposed on the north side of Salina Canyon above Twist Gulch and lying between the compact red salt-bearing shale of Twist Gulch and the diverse strata of the Morrison (?) Formation.

The Twist Gulch Member of the Arapien Shale was redesignated as a formation on the basis of its wide areal extent in Central Utah. (Hardy, 1949, p. 30)

Description. The Twist Gulch Formation was originally described by Spieker (1946, p. 124). However, in a later study Hardy (1949, p. 40) again described it at the type locality, Twist Gulch in Salina Canyon, as consisting of light-gray sandstone, maroon shale, and red siltstone in the main part, whereas the upper 175 ft. of the formation consists of olive green shale with thin layers of grit and sandstone, light-gray sandstone, and bluish-gray shale.

In the Ninemile Area there is only one exposure of the Twist Gulch Formation (Sec. 17). Here it consists of yellow-brown siltstone in the lower part and in the upper part of a red mudstone interspersed with gypsum (satinspar) veins.

Distribution, thickness, and stratigraphic relations. In Central Utah, along with the exposures east of Salina Canyon and in Salina Canyon, the Twist Gulch Formation also occurs beneath the thick Indianola conglomerate in the northern part of the Gunnison Plateau. (Hardy, 1949, pp. 31, 32) In the Cedar Hills, near the north end of San Pete Valley there are areas of Arapien Shale that probably include the Twist Gulch Formation. (Schoff, 1937, p. 29)

In the field camp area, in San Pete Valley the Twist Gulch Formation is exposed at Wales Gap, Confusion Gulch, Maple, and Pete's Canyons, Dry Canyon, and the Gunnison Reservoir Area, at the eastern base of the Gunnison Plateau. In the Ninemile Area, the Twist Gulch Formation, along with the exposure at Sec. 17, underlies the San Pete Valley between the Arapien Shale and the lower Morrison Formation, although it is covered by alluvium.

The thickness of the Twist Gulch Formation is only 75+ ft. in the Ninemile Area. But the complete section is about 3,000 feet thick in Salina Canyon as measured by plane table. (Spieker, 1946, p. 125)

In Salina Canyon the Twist Gulch is exposed in a sequence of nearly vertical beds, with the top facing east, in an angular unconformity beneath a basal red siltstone of the Flagstaff Formation. However, the Flagstaff Formation thins toward the west so that the Colton and Green River Formations directly overlie the Twist Gulch Formation. (Hardy, 1949, pp. 32, 33)

Southeast of Salina in the Sevier Valley, the Twist Gulch is exposed between the upper Arapien Shale and a conglomerate of the Flagstaff Formation. This contact is an angular unconformity. (Hardy, 1949, pp. 32, 33)

East of Redmond and south of Willow Creek, the Twist Gulch is also exposed as an angular unconformity with the Flagstaff Formation, and in this area only the basal few hundred feet of the Twist Gulch is exposed against the upper units D and E of the Arapien Shale. (Hardy, 1949, p. 32)

East of Gunnison about 300 ft. of red siltstone of the Twist Gulch Formation occurs over Unit D of the Arapien Shale. The Twist Gulch also occurs in a small syncline south of Lost Creek. (Hardy, 1949, p. 32)

In the San Pete Valley at Wales Gap, the Twist Gulch Formation has been thrust over the Morrison Formation, over parts of the Indianola Group, and the lower part of the Price River exposure. At Dry Canyon, the Twist Gulch Formation has been thrust over the North Horn Formation.

The Twist Gulch Formation is exposed along with the Morrison Formation as a thrust fault over the North Horn Formation, at the Gunnison Reservoir Area and in Pete's Canyon.

In Confusion Gulch, the Twist Gulch Formation is highly contorted and thrust faulted on vertical conglomerate of the North Horn Formation.

In the Ninemile Area, the Twist Gulch Formation is exposed in a complex structural and stratigraphic sequence. The Green River Formation has been thrust over the Twist Gulch Formation and then the Twist Gulch, Colton and Green River Formations have been thrust over this first fault.

In this area of the San Pete Valley, the Morrison Formation contact is covered by alluvium, but it is presumed that the contact is conformable.

Age and Correlation. The age of the Twist Gulch is assumed to be Upper Jurassic because of its stratigraphic position between the Arapien Shale and the Morrison Formation. There is also some paleontological evidence, since Hardy (1949, pp. 38, 70) found the Middle-Upper Jurassic forms *Echinotis* and *Ostrea* in the upper Twist Gulch of Salina Canyon.

The Twist Gulch may be in a general way equivalent to the Entrada, Curtis, and Summerville Formations of the San Rafael Group. The Entrada of the San Rafael Swell consists of red thin-bedded siltstones and massive fine-grained red sandstones which are similar to the lithologies of the Twist Gulch Formation. The upper olive green shale, light-gray sandstone, and bluish gray shale of the Twist Gulch Formation corresponds with the lithology of the Curtis Formation. The occurrence of *Echinotis* in the upper Twist Gulch Formation suggests a correlation with the Curtis Formation, because it is the only fossiliferous unit in the San Rafael Group. The light-gray sandstone, maroon shale, and red siltstone of the Twist Gulch Formation are similar to the Summerville Formation and seem to occur at the same stratigraphic position. (Hardy, 1949, p. 40)

A. A. Baker (1947, Chart No. 30) identified the relation between the Twist Gulch Formation in the northern part of the Gunnison Plateau with the Entrada Formation of the southern Wasatch Mountains and the Preuss Formation of southeastern Idaho, mainly on lithological similarities.

Morrison (?) Formation

Definition. The Morrison Formation was first defined by G. H. Eldridge (1894, pp. 60-61) from his observations near Denver and along the eastern base of the Rocky Mountains as a formation of mostly fresh water marls whose upper limit is sharply defined by the Dakota Sandstone, whereas the lower limit is a pink and brown sandstone which marks the close of the Triassic. The formation is named after the town of Morrison, Colo., where nearby it is typically developed.

However, F. H. Knowlton (1920, pp. 189-194) described dicotyledonous plant remains collected from the type section about 15 feet below the top of the formation. From this flora Ficus magnoliaefolia was positively determined to belong to the Dakota flora of the Denver Basin. The Dakota Sandstone is considered to overlie the basal Upper Cretaceous and the upper Lower Cretaceous. On this basis W. T. Lee (1920, pp. 183-184) redefined the Morrison Formation by removing the upper two units of the formation and placing them in the Dakota Sandstone. Lee then removed the lower calcareous portion (17 feet) on the basis of Sundance (Entrada) fossils. Later, J. B. Reeside (1931, pp. 1102-1103) invalidated the removal of the lower calcareous portion by re-examining the fossil evidence. He found that "Pleuromya" and other previously undetermined pelecypods were Unio felchi White and U. iridoides White and identified a species of Limnaea, a gastropod, which had not been previously noted; and that what had been thought to be Pentacrinus astericus was really Chara-like algae, which just happened to resemble crinoid stems.

Finally, A. A. Baker, C. H. Dane, and J. B. Reeside (1936, p. 31) while considering the variability and irregularity manifested by the formation deemed it legitimate to include under the name Morrison all the Jurassic Continental sediments deposited subsequent to the deposition of the San Rafael Group.

Description. The type section at Morrison, Colorado is lithologically and paleontologically different from the section cropping out on the east side of the Gunnison Plateau in the Ninemile Area.

G. H. Eldridge and S. F. Emmons (1896, pp. 22-23) described it as consisting mainly of marls with varying proportions of sandstone and thin limestone. Lenticular bodies of drab limestone occur in the clays of the lower two-thirds of the formation, which carry the remains of Sauropod and other dinosaurs and from which the name Atlantosaurus beds has been assigned. The upper third of the formation is more arenaceous, sandstone in places predominating over clays and passing into a conglomerate at the base.

W. T. Lee (1920, p. 184) described an upper unit of 150 feet consisting of variegated shale, with layers of hard sandstone and limestone containing the remains of Sauropod and other dinosaurs; and a lower unit of 10 feet consisting of sandstone with dinosaur bones and quartz pebbles. This unit fills hollows in the underlying formation.

Baker, Dane, and Reeside (1936, p. 8) described the Morrison Formation as composed of diverse sorts of rocks, mostly irregular and discontinuous beds. The most characteristic rocks are mudstones, predominantly green-gray with an admixture of red, purple, and brown, and soft whitish or greenish-white sandstones. Moreover all the beds are more or less calcareous.

In the Ninemile Area, the Morrison (?) Formation is composed of a basal oncolitic limestone unit, followed by beds of coarse purple-red and red conglomerate, yellow-brown sandstone, purple-red and red mudstones, and some limestone. Moreover, the Morrison (?) Formation here contains no fossils except the algal nodules (oncolites).

Distribution, Thickness, and Stratigraphic Relations. The Morrison Formation is presumed to cover about 350,000 square miles in parts of Utah, Colorado, New Mexico, Arizona, Wyoming and Idaho. Nevertheless, many terrestrial beds of questionable age have been called Morrison without regard to the limitations imposed by the type section and fossil evidence. (Stokes, 1944, pp. 953, 954)

In central Utah the Morrison (?) Formation is found in Salina Canyon, along the eastern base of the Wasatch Plateau, and in the Thistle area.

The average thickness at the type area according to Eldridge (1894, p. 56) was 200 feet. Lee (1920, p. 183) reduced it to 160 feet. Baker, Dane, and Reeside (1936, p. 9) noted that the thickness of the formation varies from place to place. In most of the area in which it is present its thickness is more than 500 feet. But may be as much as 850 feet, possibly more locally.

The Morrison (?) Formation in central Utah is 1300 feet thick in Salina Canyon and about 1800 feet thick in the Thistle District. In the Ninemile Area, Babisak (1949, p. 32) recorded 1857 feet. Our field group recorded 1671 feet in a traverse across Sec. 5 and 6.

At the type section the Morrison Formation is overlain by the

Dakota Sandstone and underlain by the Entrada Formation.

In Salina Canyon the Morrison (?) Formation overlies the Twist Gulch Formation, but the contact is not sharp and suggests intertonguing. (Spieker, 1946, p. 125) This locality is the only place in central Utah where the basal contact is exposed. Further, the San Pete Formation of the Indianola Group overlies the Morrison (?) Formation. However, both of these formations along with the Arapien Shale and Twist Gulch Formation have been folded, thus forming part of a limb of a monocline. Finally, these formations are truncated by the Flagstaff Limestone forming a classical unconformity.

In the Ninemile Area, the contact between the Morrison (?) Formation and the Twist Gulch Formation is covered by valley alluvium, but this contact is believed to be conformable. The San Pete Formation overlies the Morrison (?) Formation conformably. This contact is clearly visible in Sec. 6 of the map area.

Farther south, along highway 89 near Christiansburg the North Horn Formation truncates both the Morrison (?) Formation and the San Pete Formation forming an angular unconformity.

In the Ninemile Area, the Morrison (?) Formation along with the Arapien Shale, Twist Gulch, and San Pete Formation are overturned and dip steeply (40°-80° east) and the tops of the formations face west. Structurally, they form the west limb of the San Pete-Sevier Valley Anticline.

<u>Age and Correlation</u>. The age of the Morrison Formation, as determined by the study of vertebrate, invertebrate, and plant remains, is Upper Jurassic. Although these remains indicate a Jurassic age, correlation with the European type Jurassic is uncertain. (Stokes, 1944,

p. 953)

The age of the Morrison (?) Formation is probably Upper Jurassic, but paleontological evidence is lacking and the age has been determined by stratigraphic position. There is a definite lithologic change between the underlying Arapien Shale and the overlying Cretaceous San Pete Formation; however, the Morrison may also be in part Lower Cretaceous since Spieker (1949, p. 19) notes that no break in the stratigraphic record has been recognized between the Morrison (?) Formation and the Upper Cretaceous San Pete Formation.

The Morrison Formation according to Stokes (1944, p. 969) is wholly or in part equivalent to the Ephraim Conglomerate of the Gannet Group in southeastern Idaho on the basis of somewhat similar lithology, the finding of caudal vertebrae resembling Allosaurus and the occurrence of "gastroliths."

Stokes (1944, p. 969) also infers that the Beckwith Formation of southeastern Wyoming is also equivalent to a portion of the Morrison on the basis of lithology (Morrison-like bentonitic shale), which contains numerous "gastroliths."

Formerly, the term McElmo Formation of southwestern Colorado was in use but, along with the Post-McElmo Beds, it is now included by Stokes (1949, p. 967, 968) in the Morrison Formation.

In Southern Utah H. E. Gregory (1951, p. 45) believes that the Morrison Formation is absent.

Babisak (1949, p. 33-34) notes that the Morrison (?) Formation occupies a stratigraphic position similar to that of the Morrison Formation proper of the San Rafael Swell.

Spieker (1946, p. 125), Babisak (1949, p. 33) and our field group's experiences have shown that the Morrison (?) units in Salina Canyon, the Ninemile Area, Gunnison Area, and Wales Gap are equivalents on the basis of lithology and stratigraphic position.

CRETACEOUS SYSTEM

Indianola Group

The Indianola Group, the oldest Cretaceous unit in central Utah, was named and defined by Spieker (1946, p. 126) as an assemblage of conglomerate, sandstone, shale, and limestones of both continental and marine origin. At the type locality, north of Indianola, Utah, Spieker (1946, p. 127) has noted three major lithologic types:

a) buff and gray marine beds on Dry Creek

b) buff and gray continental beds on Little Clear Creek

c) Conglomerate, veriegated beds, and fresh water limestone near Hjork Creek.

Furthermore, at Indianola, the Indianola Group cannot be subdivided into formations; but near Thistle Utah, the Salina and Sixmile Canyon areas it can be differentiated into the basal San Pete Formation, followed by the Allen Valley, Funk Valley, and Six Mile Canyon Formations. At these localities the formations are truncated by the Price River Formation and younger formations.

The Indianola Group undifferentiated also occurs in the area between Salina and Gunnison, Utah, on the Gunnison Plateau, and in the Cedar Hills.

In general, Spieker (1949, p. 21) states that the Indianola Group is at least 8,000 feet thick; but in the northern part of the Gunnison

Plateau, near Levan, it may be from 8,000 to nearly 15,000 feet thick. Here the lithology is conglomerate and sandstone with locally interbedded red and variegated shale, freshwater limestone, and littoral marine sandstone.

Eastward, there is a rapid facies change from coarse to finer sediments, and the Indianola Group then becomes equivalent to the lower three-quarters of the Mancos Shale (Spieker, 1949, p. 20). Further, the age of the Indianola Group as determined by marine mollusks (<u>Corbula nematophora</u>) and fossil plants is Colorado or early Upper Cretaceous.

In the Ninemile Area, only the San Pete Formation crops out on the east side of the Gunnison Plateau, where it overlies the Morrison (?) Formation. Consequently, only a detailed presentation will be made for the San Pete Formation, and a general description will follow for the Allen Valley, Funk Valley, and Sixmile Canyon Formations.

San Pete Formation

<u>Definition</u>. Spieker (1946, p. 127) defined the San Pete Formation as a distinct unit of sandstone and conglomerate, with minor amounts of shale, containing fossils of lower Colorado age, overlying the Morrison (?) Formation and underlying the Allen Valley Shale. The formation was named by Spieker from the type locality in San Pete Valley, south of Manti Utah, where on the east side of the valley it is exposed in hogbacks and ridges.

<u>Description</u>. The general lithology of the San Pete Formation according to Spieker (1946, p. 127), consists of brown, ochre, buff and gray sandstone, gray to ochre sandy shale, and gray conglomerate. The

conglomerate occurs only in the lower part of the formation.

In the Ninemile Area, much of the San Pete Formation is covered by colluvium, especially in Sec. 6 of the map area. However, units described in a short traverse in Sec. 6 included a yellow, fine grained sandstone, a yellow-brown sandstone interbedded with shale, yellow-brown shaly sandstone, a pale yellow sandstone, and a gray-brown conglomeratic sandstone. Fossils were not found in any of these units.

Distribution, Thickness, and Stratigraphic Relations. In addition to the exposures in San Pete Valley, the formation is also present in Salina Canyon and southeast of Thistle.

In the Ninemile Area, the formation is exposed only on the eastern part of the Gunnison Plateau in two separate areas, one in Sec. 6 and the other in Sec. 7.

In Salina Canyon, there is a complete, well-exposed section of the formation, where it is about 1350 feet thick (Spieker, 1946., p. 127). However, in the Ninemile Area it is only up to 725 feet thick.

The San Pete Formation is underlain conformably by the Morrison (?) Formation in the Sixmile Canyon Area, Salina Canyon, and in the Ninemile Area.

In Salina Canyon the San Pete Formation lies adjacent to the Allen Valley Shale, both formations dipping 30° East, and truncated by the basal Flagstaff Formation in angular unconformity.

In the Sixmile Canyon area, the San Pete Formation lies adjacent to the Allen Valley Shale, both formations dipping East.

In the Ninemile Area, the San Pete Formation dips 35°-40° East and overturned is truncated by the North Horn Formation, which dips 25° West, forming an angular unconformity.

Age and Correlation. The age of the San Pete Formation, on the basis of fossil evidence has been determined as lower Colorado.

Spieker (1949, p. 11 and 1946, p. 121) also notes that the San Pete Formation is equivalent to the Tununk Shale of the Mancos Formation. A similar facies has been recognized by C. H. Wegemann (1913, p. 163) in the Coalville district, and by G. B. Richardson (1927, pp. 464-475) in the Kolob Plateau.

Allen Valley Shale

Spieker (1946, p. 127) designated a body of marine shale, between the sandstones of the San Pete and Funk Valley Formation, , as the Allen Valley Shale. The type locality is 3 miles southwest of Manti in Allen Valley, and the only other exposure is in Salina Canyon.

The Allen Valley Shale consists of evenly bedded gray marine shale, interbedded with thin layers of yellowish bentonite, siltstone, very fine grained sandstone and gray limestone. The beds are relatively thin, about a foot thick, and range in texture from a trace of sand present to very sandy.

In the Sixmile Canyon area, the Allen Valley Shale is overlain by the Funk Valley Formation and underlain by the San Pete Formations, all of them dipping East.

In Salina Canyon, the Allen Valley Shale lies between the San Pete Formation and Funk Valley Formations and the formations dip 30° East. Further, the Flagstaff Formation truncates the Allen Valley Shale, forming an angular unconformity.

The thickness of the formation is 650 feet in the type area and 850 feet in Salina Canyon.

J. B. Reeside (1926, p. 432-435) identified fossils from the Allen Valley Shale as of middle Colorado (Carlisle) age. This indicates that the formation is equivalent to the Ferron Sandstone Member of the Mancos Shale. C. H. Wegemann (1915, pp. 161-184) found shale of the same age in the Coalville region, and in southwestern Utah. Spieker (1946, p. 128) further notes that the formation may be widespread in a belt trending a little east of north through central Utah.

Funk Valley Formation

Spieker (1946, p. 128) defined the Funk Valley Formation as a unit of marine sandstone and shale overlying the Allen Valley Shale. The type locality is Funk Valley, 3 to 4 miles southwest of Manti, Utah, where Spieker (1946, p. 128) has subdivided the formation into three members.

At this locality the measured thickness is 2250 feet, but in Salina Canyon only the basal 600 feet of the formation is exposed.

In Sixmile Canyon, the Funk Valley Formation is truncated by the almost horizontal Flagstaff Formation, which forms part of the limb of the Wasatch Monocline.

In Salina Canyon, the Funk Valley Formation lies between the Allen Valley Shale and the Sixmile Canyon Formation, all formations dipping about 30° East and truncated by the Flagstaff Limestone forming an angular unconformity.

On the basis of fossils found in the two sandstone members, the age of the Funk Valley Formation is at least middle Colorado. Further, the formation is equivalent in part to the Blue Gate Shale of the Mancos Formation in Castle Valley (Spieker, 1946, p. 128; 1949, p. 11). It is likely that the formation also has counterparts in the Coalville-Evanston and the Kaiparowits-Kolob Regions.

Six Mile Canyon Formation

E. M. Spieker (1946, p. 128) defined the Sixmile Canyon Formation as a thick succession of coarse grained gray sandstone and conglomerate containing a coal member of finer grain. At the type section, Sixmile Canyon, just east of Funk Valley, Spieker (1946, p. 128) subdivided the formation into three members. At the type locality the formation is probably more than 2,800 feet thick. The Sixmile Canyon Formation is also exposed in Salina Canyon.

In the Sixmile Canyon area, the Sixmile Canyon Formation is underlain by the Funk Valley Formation, both formations dipping east. It is overlain mostly by the Price River Formation and Flagstaff Limestone forming a sharply defined angular unconformity.

This complex relationship has been unravelled by Spieker (1949, p. 50) as an older easterly dipping monocline overlain by the younger westerly dipping Flagstaff Limestone, which forms part of the Wasatch Monocline. According to Spieker (1949, p. 50) younger formations were deposited over the Flagstaff Limestone, but they were subsequently eroded.

In Salina Canyon, the Sixmile Canyon Formation is underlain by the Funk Valley Formation, both formations dipping east. The overlying Price River, and Flagstaff Limestone truncate the Sixmile Formation forming an angular unconformity.

R. W. Brown and J. B. Reeside in 1935 and 1936 determined, from fossil plants and mollusks collected from the coal-bearing member, that the Sixmile Canyon Formation was of upper Colorado age.

Spieker (1946, p. 128; 1949, p. 11) correlated the formation with the upper part of the Blue Gate Shale Member of the Mancos Shale in Castle Valley. Similar coal-bearing rocks of Colorado age are also found in southern Utah.

Finally, it will be noted, that although the Price River Formation is widely distributed in central and eastern Utah, it is absent in the Ninemile Area, thus representing a disconformity between rocks of the Indianola Group and the North Horn Formation.

CRETACEOUS AND TERTIARY SYSTEMS

North Horn Formation

Definition. Spieker (1946, pp. 132-133) redefined the lower member of the Wasatch Formation as the North Horn Formation. The type locality is on North Horn Mountain in the east-central part of the Wasatch Plateau, where it has been subdivided into four basic units.

Description. The North Horn Formation according to Spieker (1946, p. 123; 1949, p. 26) consists of variegated shales with associated sandstones, conglomerates, and fresh water limestones. This general facies is most widespread in the central and southern parts of the Wasatch Plateau. In the northern part of the Wasatch Plateau and in the Cedar Hills the formation is dominantly red, and contains more conglomerate.

In the Gunnison Plateau, Spieker (1949, p. 29) describes three rapidly changing facies of the formation. At Wales Gap, it consists of an upper limestone member with beds of coal and oil shale and a lower member of shales and sandstones. But at Peach Canyon, about a mile southward, the formation changes abruptly to a massive sandstone and conglomerate facies. Five miles farther south, in Dry Canyon, the formation changes again into the general facies of the Wasatch Plateau, then south of Dry Canyon the formation appears as gray shale and calcareous siltstone. In another locality, the Valley Mountains, southwest of the Gunnison Plateau, the formation changes westward to a distinctive brown sandstone and a subsidiary red shale.

In the Ninemile Area, the North Horn Formation consists of pale yellow and yellow brown sandstones, prominent channel conglomerates, red-brown to red mudstones, interspersed with a thin bed of yellow-brown sandstone, and an uppermost bed of gray-brown conglomerate with numerous large oncolites.

Distribution, Thickness and Stratigraphic Relations. The North Horn Formation is widely distributed in central Utah. Spieker (1949, p. 26) notes that it makes up most of the main body of the western half of the Wasatch Plateau, is the dominant formation in the Valley Mountains, and is prominent in the Pavant Range and in Long Ridge, west of Juab Valley.

In the Ninemile area, the North Horn Formation is exposed only in the south eastern foothills of the Gunnison, from a point on the west side of Highway 89, near Christianburg, northward as far as the west side of the Gunnison Reservoir, where it pinches out against the Flagstaff Limestone and the cover of valley alluvium.

The maximum thickness of the formation is 9,000 feet near the

Cedar Hills. It is 2,800 feet or more in the Gunnison Plateau and the Valley Mountains, 1,500 to 2,000 feet in the Wasatch Plateau, and only 500 feet thick in lower Salina Canyon. In the Ninemile area, the maximum thickness is 385 feet, but it may thin out to 50 feet.

The North Horn Formation according to Spieker (1946, p. 133) grades downward into the sandstone and conglomerate of the Price River Formation and passes transitionally upward into the Flagstaff Limestone in most places in central Utah.

In Sixmile Canyon, the Flagstaff Limestone overlies the North Horn Formation, along with the older Price River and Sixmile Canyon Formations, in an angular unconformity. This unconformity is the main evidence for pre-Flagstaff monoclinal folding and subsequent erosion before the deposition of the Flagstaff Limestone. This event as described by Spieker (1946, p. 133) is in contrast with the formation relationships on the western piedmont of the Wasatch Plateau, where the angular contact between the Flagstaff Limestone and older rocks is a thrust fault. In Salina Canyon the Flagstaff Limestone also truncates the North Horn Formation and older rocks forming an angular unconformity that has not been deformed by thrust faulting. (Spieker, 1946, p. 134)

In the Ninemile area, the North Horn Formation overlies the Morrison (?) Formation and the San Pete Formation in an angular unconformity. In Sec. 6 of the map area, the North Horn Formation dips 25° to 30° West and the Morrison (?) Formation and the San Pete Formation dip about 35°-40° East. In the S.W. $\frac{1}{4}$ of Sec. 6, a rotated fault block has exposed an underlying band of the San Pete Formation between the upper and lower fault blocks.

Near Christianburg, at a point on the west side of Highway 89, the Flagstaff Limestone overlies the North Horn Formation in a slight angular unconformity. Babisak (1949, p. 47) traced the ledge of Flagstaff Limestone northward to the main part of the Gunnison Plateau, where this ledge lies 200 feet above the North Horn Formation as compared with about 15 ft. near Christianburg. Hence, the inference that the Flagstaff Limestone was deposited on a surface of considerable relief cut into the North Horn Formation. The North Horn Formation dips about 30° West, and the Flagstaff dips about 25° West, farther north in Sec. 6 of the Ninemile Area the contact is almost conformable, and in Maple Canyon it finally becomes conformable.

Age and Correlation. The age of the North Horn Formation (Spieker, 1946, p. 139-145; 1949, p. 28) is based mostly on paleontological evidence. J. B. Reeside identified numerous species of fresh water mollusks, collected from the lower part of the formation east of Mt. Pleasant, Utah, as of Upper Cretaceous age. Then Reeside and Spieker, in 1935, collected vertebrate fossils on North Horn Mountain, later identified by C. W. Gilmore as distinctive of the Upper Cretaceous. However, the middle 600 feet of the formation, after careful search by Gilmore, Spieker et. al., yielded only undiagnostic fossils. To further complicate the stratigraphy, the upper part of the formation contains mammalian bones of Paleocene age. Thus the formation contains rocks of both Cretaceous and Tertiary age, and further no new evidence has been unearthed to place a limiting line somewhere between the two ages of the formation.

In review then, it is evident that regional and local correlation of the North Horn Formation is often difficult because of rapid facies changes and other lithologic anomalies, along with the lack of diagnostic fossils in key areas.

Spieker (1946, p. 135) correlates the North Horn in part with the Lance and Ft. Union Formations of the northern plains and with the Ojo Alamo, Puerco, and Torrejon Formations of the San Juan Basin (northwestern New Mexico) on fossil evidence. Locally, (Spieker (1949, p. 28) the formation will intergrade and intertongue with the Price River and Flagstaff Formations.

TERTIARY SYSTEM

Flagstaff Limestone

Definition. Spieker and Reeside (1925, p. 448) first defined the Flagstaff Limestone as the middle lacustrine member of the Wasatch Formation. Later, Spieker (1946, p. 135) elevated it to formation rank on the basis that it contains fossils older than Wasatch in age, and also because in thickness and extent it is a major stratigraphic unit in the region. Further, the Flagstaff Limestone is more closely related to the Green River Formation than to the North Horn and Colton Formations, which are flood-plain deposits.

Description. Although the formation is chiefly fresh-water limestone, it may also be interbedded with shale and minor amounts of sandstone. Locally, it may also contain gypsum, volcanic ash, oil shale and other bituminous and carbonaceous beds, and conglomerate.

Specifically, the limestone may be dark gray with fossils, dark gray, massive, relatively unfossiliferous, and cream to light tan resembling lithographic limestone. Chert beds, nodules, and algal limestone are abundant. The limestone may be brecciated or fragmented (Spieker, 1949, p. 31)

In the Ninemile area, the Flagstaff Limestone is of the gray, unfossiliferous variety. The resistant beds, which form ridges, are silicified and often jointed. The limestone is interbedded with shaly beds that have weathered to mudstone. Honeycomb weathering is also evident in the silicified limestone beds.

Distribution, Thickness, and Stratigraphic Relations. According to Spieker (1949, p. 30) the Flagstaff Limestone is the most prominent formation in the area. It forms the white cliffs at the top of the Wasatch Plateau, and on the western flank of the plateau it forms the dip slopes of the Wasatch Monocline as far south as Sixmile Canyon. It caps the eastern front of the Gunnison Plateau, and west of the Gunnison, it is present in the Valley Mountains, on Long Ridge, and in the Pavant Range. On the south, it is exposed on the Fish Lake Plateau. And finally, it also occurs in the area north of the Book Cliffs (Spieker, 1949, pp. 30-31; Babisak, 1949, p. 51).

In the Ninemile area, there are two separate exposures. In the west, it caps the foothills of the Gunnison Plateau, and in the gulch, south of Highway 89, in Sec. 17, there is a small, but important outcrop.

The thickness of the formation varies between 300 to 800 feet. However, in the southern part of the Wasatch Plateau, in the Valley Mountains, and in the Pavant Range, it may be 1500 feet or more in thickness.

In the Ninemile area, the maximum thickness of the formation is about 565 feet, although the formation decreases in thickness to about 350 feet farther south in the map area.

The stratigraphic relations between the Flagstaff Formation and older rock-stratigraphic units were discussed in the preceding section on the North Horn Formation.

In general, the Flagstaff Formation is overlain by the Colton Formation. J. R. Gill (1950, pp. 18-19) in his comprehensive study of the Flagstaff, remarks that from place to place the contact between the formations may be either gradational or sharp and clear.

Spieker (1946, p. 136) notes that at Thistle the Colton Formation is absent, because of a westward facies change from the red beds and sandstones of the Colton Formation to the shales, sandstones, and limestones of the Green River Formation. Thus, in the Thistle District the Flagstaff Limestone is overlain by the Green River Formation. Further, Spieker explains that the Flagstaff Formation in this area has the form of a tongue of the Green River Formation. East of Thistle the Flagstaff Formation intertongues with the Colton Formation.

In the Ninemile area, in Sec. 17, the small exposure of the Flagstaff Limestone is of importance, because this indicates that the formation was deposited in an angular unconformity over the Twist Gulch and Arapien Shale. Thus the Flagstaff Formation was also involved in the post-Green River thrust faulting in this area.

Age and Correlation. Spieker (1946, p. 136) on the basis of some paleontological evidence (fresh-water mollusks) and its stratigraphic position, overlying the North Horn Formation, was inclined to favor a Paleocene age for the Flagstaff Limestone. However, Gill (1950, pp. 118

and 154) found forms, including <u>Goniobasis</u> <u>tenera</u> Var. C, in the upper part of the formation that are characteristic of the Eocene. Therefore, Gill favors an upper Paleocene age for the lower part of the formation, and an early Eocene age for the upper units.

La Rocque (1956, p. 141) on the basis of further paleontological study, infers that the formation was deposited from medial Paleocene to early Eocene, and in some places middle Eocene time.

Gill (1950, p. 119) states that none of the Paleocene formations have ever been traced into strata of the Flagstaff Limestone. However, since the Flagstaff intertongues with the Colton and the North Horn Formations, it is therefore partly contemporaneous with them. The formation may also be equivalent in part to the Knight and Almy Formations of the Wasatch Group of southwestern Wyoming, along with the uppermost Fort Union strata of the northern Great Plains. (Gill, 1950, p. 120) and (Gilliland, 1948, p. 65)

Finally, on the basis of lithological similarities, Spieker (1949, p. 32) and Gilliland (1948, pp. 65-66) correlate the Flagstaff Limestone with the Wasatch Formation of the Bryce Canyon-Cedar Breaks area.

<u>Colton Formation</u>

<u>Definition</u>. The Colton Formation was defined by Spieker (1946, p. 139) as consisting of the beds in the hills north of Colton, Utah between the Flagstaff Limestone and the Green River Formation. The Colton Formation was formerly the upper member of the Wasatch Formation.

<u>Description</u>. The generalized description of the Colton Formation by Spieker (1946, p. 139) at the type locality consists of beds of gray,

pepper-and-salt sandstone, greenish buff sandstone, and siltstone that commonly weathers golden brown, and shale ranging from deep red to variegated and gray in color.

In the Ninemile area, the formation is comprised of shaly, red mudstone, brown mudstone interbedded with micaceous sandstone, and a green mudstone interbedded with a marly limestone.

Distribution, Thickness and Stratigraphic Relations. The Colton Formation is restricted to the northern and western margins of the Wasatch Plateau, the body of the Gunnison Plateau, and the southeastern margin of the Valley Mountains. (Spieker, 1949, p. 34)

In the Ninemile area, the formation occurs in the gulch south of Highway 89 in Sec. 17. There are also small exposures in Sec. 8, south of the Gunnison Reservoir, and on the west side of Arapien Valley in Sec. 17 of the map area.

The Colton Formation according to Spieker (1949, p. 34) is generally from 300 to 1,000 feet thick, but on the western Wasatch and West Tavaputs Plateau it may range from a trace at the edge of a tongue to more than 1600 feet in thickness. Hunt (1956, p. 18) claims a maximum thickness for the formation of about 2,000 feet along the Green River. It thins to the west by grading into or intertonguing with the underlying Flagstaff and overlying Green River Formations.

In the Ninemile area, the Colton Formation overlies the Arapien Shale in Sec. 8 but this appears to be the result of the post-Green River thrust faulting. In Sec. 17, the Colton Formation overlies the Twist Gulch, and in one place it overlies the Flagstaff Formation. This is the result of both thrust faulting and a high angle normal fault trending approximately north and south. Overlying the Colton Formation in the area is the Green River Formation. In the Ninemile Area, the measured section was only 284 feet thick in Sec. 17 of the map area.

Age and Correlation. Spieker (1949, p. 139) inferred from the paleontological and stratigraphic evidence, that the Colton Formation was of lower Eocene age. La Rocque (1956, p. 141) on the basis of fresh water mollusks also dated the Colton as Eocene in age.

H. E. Wood (1941, p. 1) correlates the Colton Formation with the upper formations of the Wasatch Group of central Colorado and southeastern Wyoming. The Colton Formation is also presumed to be equivalent to the lower Green River Formation in southeastern Wyoming and north of the Wasatch Plateau. The Colton Formation is probably equivalent to the Wasatch Formation of the Piceance and Uinta Basins.

Green River Formation

Definition. F. V. Hayden (1869, p. 90) named and defined the Green River Formation as a series of thin, laminated, calcareous shales that are exposed along the Green River near Rock Spring station, Wyoming. The type locality is at Green River, Wyoming.

Description. According to W. H. Bradley (1931, p. 9) most of the formation at the type locality consists of finely laminated marlstone, some of which is oil shale. Bradley has subdivided the formation into the following three members:

a) The Tipton Shale Member - This is the basal unit and consists of calcareous or sandy shale and marlstone that weathers buff or gray buff.

b) The Laney Shale Member - This member is divided into two units. The lower one contains more marlstone and sandstone and weathers a dull gray. The upper unit is nearly all finely laminated marlstone, shale, and oil shale and weathers stark white.

c) The Morrow Creek Member - This upper member is comprised mostly of crudely bedded sandy and calcareous shale or shaly marlstone that weathers yellowish-brown.

At the type locality the Green River Formation includes the Tower Sandstone Lentil, 125 to 245 feet thick, at the top.

The Green River Formation has a complex lithology and a wide areal extent, and for these reasons Bradley divided the lithologic description into two parts, thus covering the rocks east and west of Bitter Creek, Utah.

East of Bitter Creek,Utah the formation has been subdivided into four members:

a) The Douglas Creek Member - This is the basal member composed of 200 to 800 feet of buff or yellow-brown shale containing considerable sandstone, marlstone, algal reefs and oolite.

b) The Garden Gulch Member - This member is composed of 200 to 700 feet of marlstone or organic-rich shale in paper thin laminae and some fine-grained sandstone and siltstone.

c) The Parachute Creek Member - This member is distinguished from other parts of the formation by its content of oil-shale beds. It contains all the large groups of rich beds, most of the individual rich beds, and a very large proportion of the low-grade shale. This oil-shale facies of the Green River Formation reaches its maximum thickness and probably its maximum richness in the vicinity of Parachute Creek, Colo. The thickness ranges from 175 feet at Watson, Utah to 1,000 feet at Parachute Creek.

d) The Evacuation Creek Member - This upper member consists chiefly of barren shale and marlstone. It is 2,000 feet thick in the western part of the Uinta Basin, but thins eastward to 500 feet.

In central Utah Spieker (1949, p. 35) states that the Green River Formation is somewhat different from the facies of the Uinta Basin and western Colorado. Here, the formation consists of two members, both about 100 to 400 feet thick. The lower member is a blue-gray to light blue shale, and the overlying units are cream to tan shale. This upper member, locally, contains oolites and numerous volcanic ash beds.

In the Ninemile area, the upper limestone member represents the majority of the formation. Nevertheless, the lithology is varied. At the base of the formation there is a green mudstone interbedded with shale, which is followed by a relatively thin bed of micaceous siltstone. These beds are overlain by a calcareous light-brown mudstone, a gray siltstone interbedded with an oolitic limestone bed, tuff beds, a massive gray limestone bed, and finally a green and brown mudstone interbedded with shale.

Distribution, Thickness and Stratigraphic Relations. The Green River Formation is widely distributed in parts of Wyoming, Colorado, and Utah. It underlies the Uinta Basin and extends northward into the Wyoming Basin. It also occurs in the Piceance Basin of western Colorado. These two structural basins are connected by a narrow isthmus of the formation. (Bradley, 1931, p. 1)

In central Utah Spieker (1949, p. 35) notes that the formation is exposed mainly at the base of the Wasatch Plateau on the north and west, and in the upper levels of the Gunnison Plateau. It also occurs at the bases of the Valley Mountains and the Pavant in the vicinity of Round Valley. In the Ninemile area, it forms the outer flank of the Wasatch Monocline.

At the type locality the Green River Formation is 1350 feet thick. In the Uinta Basin, it may range in thickness from 1,100 to 4,000 feet, and north of the Wasatch Plateau its maximum thickness is 6,000 feet or more. In central Utah the formation may be up to 800 feet thick, and in the Ninemile area it is approximately 625 feet thick.

In eastern Colorado, southern Wyoming, and eastern Utah the Green River Formation is overlain by the Bridger Formation. The contact is, in general, conformable, but Bradley (1931, p. 22) notes the possibility of an angular relationship between the two formations on the northern edge of the Uinta Basin. The Green River Formation overlies the Colton or its equivalent, the Wasatch Formation of the Uinta and Piceance Basins.

In central Utah the Green River Formation conformably overlies the Colton Formation. In the Arapien Valley, the Green River Formation has been deposited in angular unconformity with the Arapien Shale and later thrust faulted along the unconformity. Overlying the Green River Formation disconformably is the Crazy Hollow Formation.

In the Ninemile area, the Green River Formation overlies the Colton, but in some places it also overlies the Arapien Shale in an angular unconformity. This relationship may be in part depositional since it appears that there has also been thrust faulting in the area.

Age and Correlation. E. W. Berry (1925, p. 360) on the basis of paleobotanical evidence, assigns a middle Eocene age to the Green River Formation. Spieker (1949, p. 13) also classifies it as middle Eocene, mostly on the basis of stratigraphic position.

Regional correlation is difficult because of the position of the Green River Formation as the uppermost unit in many areas. However, Berry (1925, p. 360) expressed the opinion that the Green River Formation can be correlated with the Auversian stage of the European section.

Crazy Hollow Formation

Definition. The Crazy Hollow Formation was defined by Spieker (1949, p. 36) as the unit of red and orange sandstone, siltstone, shale, white sandstone, and salt-and-papper sandstones that overlies the Green River Formation and underlies the Gray Gulch Formation. The type locality is in Crazy Hollow on the south side of Salina Canyon.

Description. In the Ninemile area, the Crazy Hollow Formation consists of a gray micaceous sandstone, a coarse dark gray conglomerate with jasper pebbles, and units of gray and red cross-bedded sandstone.

Distribution, Thickness, and Stratigraphic Relations. The Crazy Hollow Formation is scattered over a wide area in central Utah. Along with the exposures in Crazy Hollow and the district to the south, it is also exposed at the base of the Wasatch Monocline between Willow Creek and Salina Creek, and in the foothills of the Wasatch Plateau immediately to the west. It occurs on Temple Hill near Manti, near

Spring City, and in the southern part of San Pete Valley. It is also present on the west side of the Gunnison Plateau. (Spieker, 1949, p. 36)

In the Ninemile area there is a small exposure capping the east side of the gulch in Sec. 17. The most prominent exposure occurs on the flank of the monocline in Sections 15 and 22 of the map area.

The thickness of the Crazy Hollow Formation at the type locality is about 600 feet near the northeast corner of the Gunnison Reservoir. Babisak (1949, pp. 67-70) measured 428 feet of the Crazy Hollow Formation. In the Ninemile area, the thickness is about 80 feet in Sections 15 and 22, and only about 15 feet in Sec. 17.

Spieker (1949, pp. 35, 36) claims that where its base can be clearly seen, the Crazy Hollow lies disconformably on the Green River Formation or on older beds, and in the Crazy Hollow-Twist Gulch district it was deposited on a surface of some relief. In Twist Gulch there is evidence of a post-Green River, pre-Crazy Hollow epoch of faulting and erosion, causing the Crazy Hollow beds to rest locally in angular unconformity on the Arapien Shale. Finally, where observed, the Green River and the Crazy Hollow Formations have parallel attitudes.

The Crazy Hollow Formation is disconformably overlain by pyroclastic sediments of the Gray Gulch Formation and the siltstones of the Bald Knoll Formation.

Age and Correlation. On the basis of stratigraphic position Spieker, (1949, p. 36) assigns an Eocene or possibly a late Eocene age to the Crazy Hollow Formation.

The Crazy Hollow Formation has not been correlated with any other formation in the region.

Axtell Formation

Definition. The Axtell Formation was defined by Spieker (1949, p. 39) as the youngest bedrock in the area. It is mainly a conglomerate containing pebbles, cobbles, boulders of all other bedrock formations including the lava beds. The type locality is two miles east of Axtell, Utah.

Description. In San Pete County the Axtell Formation most commonly occurs as a dissected alluvial fan rimming the western margin of the Sevier River Valley at the foot of the Valley Mountains. (Pratt and Callaghan, 1970, p. 46) The formation ranges in color from gray to buff to orange-brown. It is poorly sorted and lightly indurated in a silty and clayey matrix. The dominant rock type is limestone fragments. The formation may also contain thin sandstone beds.

In the Ninemile area the formation is a yellow-brown conglomerate in Sec. 18, but in Sec. 19 it consists of light gray limestone clasts. At both exposures the rocks are lightly indurated.

Distribution, Thickness, and Stratigraphic Relations. Along with the occurrences at the type locality, the formation is also present on a small hill east of the Gunnison Reservoir, in the foothills below the Wasatch Plateau, southeast of Gunnison, and at the foot of the Valley Mountains.

Spieker (1949, p. 38) notes that at the type locality the Axtell Formation is about 50 to 75 feet thick. It dips northward about 21° in angular unconformity over the Green River Formation. Since the high angle of tilt does not appear to be the original mode of deposition, it is probable that the tilt was caused by post-depositional warping.

In Sections 18 and 19 of the Ninemile area the Axtell Formation overlies the Arapien Shale in angular unconformity. There are also isolated remnants of the formation along the lower foothills of the Arapien Shale. In this area the Axtell Formation may be up to 25 feet thick, especially in Sec. 19, northwest of Mayfield, Utah.

Age and Correlation. The age of the Axtell Formation is largely determined by its stratigraphic position. Since it lies above the lava beds it is probably late Tertiary, and since it was deposited on low-lying surfaces much like the present ones, it may also be partly Quaternary in age.

The Axtell Formation has been difficult to correlate outside the San Pete-Sevier Valley area, because of its discontinuous nature and relatively minor occurrences. Gilliland (1948) suggests that the formation may be equivalent to the Sevier Valley and Parunaweap Formation farther south, in Utah.

STRUCTURAL GEOLOGY[1]

REGIONAL STRUCTURE

Central Utah lies in the transition zone between the Colorado Plateaus and the Great Basin. Bordering the San Pete and Sevier Valleys on the east is the Wasatch Plateau, which embodies features of both provinces. In the eastern part of the plateau the rocks dip gently to the west, and in the central part of the plateau, where the rocks are nearly horizontal, they form broad swells and depressions, which have been broken by systems of high-angle normal faults. These faults have resulted in five major graben trending north-south on the

[1]Modified after Spieker, E. M., 1949, pp. 39-77.

top of the plateau. Further, these graben are distributed across the plateau en echelon from northeast to southwest.

On the northern border of the plateau the rocks plunge toward the western end of the Vinta Basin in the Soldier Monocline, and on the west they plunge into the San Pete and Sevier Valleys on the Wasatch Monocline.

In the central part of the region, two large structural depressions form the San Pete and Sevier Valleys. They are both underlain by the titanic San Pete-Sevier Anticline.

The Gunnison Plateau borders the San Pete Valley on the West. This plateau also lies in the transition zone between the two provinces. On the western and eastern margins of the plateau normal faulting has taken place. This is further complicated by numerous thrust faults on the eastern side of the plateau. The center of the plateau is underlain by horizontal or gently dipping rocks. In a motor traverse across the Gunnison Plateau, it was ascertained from the attitude of the rocks from Wales Gap to Levan, Utah, that the plateau is a broad syncline.

LOCAL STRUCTURE

The Ninemile area has several interesting structural features that are of importance to the overall geology of the region. Two of the most striking structural features are the remnants of the San Pete-Sevier Valley anticline, and the presence of the outer flank of the Wasatch Plateau. Subsidiary features are the numerous normal faults, the presence of a large thrust sheet, and the synclinal nature of the Arapien Valley. Several angular unconformities are present in the area.

All of the features are of importance in the orogenic and geologic history of the area. Each of these features will be examined in detail.

Folds

San Pete-Sevier Valley Anticline. W. N. Gilliland (1963, p. 115) describes the San Pete-Sevier Valley anticline as a very large, slightly sinuous anticline with a highly mobile shale (Arapien Shale) core trending north-south in Sevier and Sanpete Counties. It is 65-70 miles long and has structural relief of possibly 15,000 to 20,000 feet.

The fold had its inception no later than the early Laramide orogeny and was probably initiated by compression. Later, the highly mobile Arapien Shale flowed toward the axial area because of renewed compression as well as geostatic pressure. As a result the Arapien has been topographically high almost constantly since its exposure following the early Laramide orogeny. As a further result, all the stratigraphic units, with possibly one exception, deposited in the area since the early Laramide orogeny are known to overlap the Arapien core, and many locally dip away from it.

Some of the unconformities in the immediate vicinity of San Pete and Sevier Valleys, which were previously interpreted as indicators of compression, may more correctly reflect the upwelling of the Arapien Shale, and the attendant tilting of the overlapping strata. (Gilliland, 1963, p. 115)

The evidence for the existence of an anticline in the Ninemile area was obtained by taking the attitudes of the different formations. On the Gunnison Plateau the Morrison and San Pete Formation are overturned, as ascertained from cross-bedding, and dipping to the east. The amount of dip decreased from 80° to 35° in a traverse across the "Red Hills." However, on the east side of the valley the underlying formations are obscured by alluvium and the Green River Formation. From our traverse across the Sixmile Canyon area, near Palisade Lake, we were aware that the Morrison Formation and formations of the Indianola Group were exposed on the east side of the valley dipping about 45°-50° to the east. From the strike of the formations at this locality, it became apparent that formations were covered under the flank of the Wasatch Monocline in the Ninemile area. Since the Arapien Shale is the oldest exposed formation in the area, it was assumed to be the core of the anticline. In Sec. 7, the San Pete Formation was observed to be dipping west about 6° and overturned, whereas nearby beds of the same formation are dipping 65° east and also overturned. This sudden change in dip is the basis for assuming the San Pete-Sevier Valley anticline to be a fan-shaped fold.

Wasatch Monocline. The Wasatch Monocline, because of its magnitude, is a classic example of this type of folding. The monocline extends for more than 60 miles along the western front of the Wasatch Plateau and has a maximum displacement of 8500 feet. The basis for calling this structure a monocline is also the attitude of the formations. Near the top of the plateau the formations are almost horizontal. On the flank of the monocline the dip increases from a few degrees to about 30° west. However, in the Ninemile area, near the base of the formation the dip decreases to about 12° west.

Mayfield Syncline. The Arapien Valley is structurally a syncline.

The Green River Formation dips into the valley at about 12°, but instead of disappearing under the alluvium it emerges on the other side of the valley, forming its west wall. The formation on the west side of the valley dips about 25° to the east. Thus the structure is an asymmetrical syncline. Along with the Green River Formation, beds of the Colton, and Flagstaff Formations are also involved in the fold.

Faults

Antithetic Faults. The Wasatch Monocline is fractured near the base by four nearly parallel, high-angle, normal faults. The faults dip about 85° east and the displacement may be as much as 180 feet. The strike of these faults is essentially north. Physical evidence for these faults can be seen on the north wall of Twelvemile Canyon, east of Mayfield, Utah. The trace of the faults could also be seen on aerial photographs.

Thrust Fault. West of the Arapien Valley, rocks of the Flagstaff, Colton, and Green River Formations overlie the Twist Gulch and Arapien Shale. This relationship is in part an angular unconformity, but it also appears that the younger rocks have been thrust over the older formations. The evidence for this movement is based on the theory that as the more mobile Arapien Shale was involved in orogenic movement independent of the other formation, the more competent limestone beds slid along the unconformity. An in Sec. 18 of the Ninemile area a sharp, clear contact between the Green River Formation appears to be the result of a thrust fault. (Billings, 1933, pp. 153-155)

Normal Faults. In the Ninemile area, on the lower Gunnison

Plateau, a normal fault has displaced rocks of the North Horn Formation revealing the underlying strata of the San Pete Formation. A high-angle fault has displaced the strata on the Arapien hogback near the Ninemile Reservoir.

Spieker (1962) believes that a fault or fault zone near the west edge of the San Pete Valley accounts for the uplifted east side of the Gunnison Plateau. The fault or fault zone has a displacement of near zero feet at the extreme south end of the plateau to over 8,000 feet north of Ephraim. (Gilliland, 1963, p. 119)

Unconformities. There are numerous unconformities in the Ninemile Area. The Crazy Hollow Formation overlies the Green River in a disconformity. The Green River, Colton, and Flagstaff Limestone overlie the Arapien Shale and Twist Gulch Formation in an angular unconformity. The North Horn Formation truncates both the Morrison and San Pete Formations. The Flagstaff overlies the North Horn Formation in a slight angular unconformity. Finally, the Axtell Formation overlies the Arapien Shale in angular unconformity.

ECONOMIC GEOLOGY

Sanpete County has never been the site of a major mineral discovery, but extensive natural resources are continually being developed.

One of the most important resources is the water supply. In this respect, the people of the valley have been fortunate. Nevertheless, all available water supplies are covered by riparian rights, therefore all new commercial and agricultural enterprises must seek to purchase their own water supplies. (Pratt and Callaghan, 1970, p. 21)

The major sources of ground water are fault springs and artesian wells. The thick alluvial fill, about 500 feet, in the Manti-Ephraim area, along with porous beds in the Crazy Hollow, Green River, Colton, Flagstaff, and North Horn Formations may provide reservoir rock for the flow of water from the highlands of the Wasatch Plateau. Faults and associated structures along the west side of the valley provide a dam against further westward migration of artesian water, and escape into Sevier Valley is blocked by bedrock exposures of the Green River Formation on Arapien Shale near Sterling. (Pratt and Callaghan, 1970, p. 26)

Moreover, the water supplies are carefully managed. A system of reservoirs and irrigation canals are used to supply the surrounding farms and ranches during the whole year. Ground water supplies are conserved by the use of surface water in times of high precipitation. Water used for washing coal, sand, and gravel is often recycled. The quality of the ground water in the San Pete Valley is good and becomes better with depth in the alluvial fill. Water near and around the Arapien Shale is moderately saline, and water from the Green River Formation may be very hard. (Pratt and Callaghan, 1970, pp. 26-35)

Industrial minerals and rocks are abundant in the San Pete Valley. Limestone, dolomite, and dolomitic limestone suitable for construction purposes are widely distributed in the Flagstaff Limestone and Green River Formation. The oolitic limestone of the Green River Formation and sandstone from the Crazy Hollow Formation are often used as building stone.

Welded tuff from the Goldens Ranch Formation, in western Sanpete County is quarried, crushed, and finely ground and then marketed under the trade name of "Azomite." It is used as poultry grit, a feed additive for domestic animals, and as a soil conditioner. Fuller's earth has been prospected for in the Green River Formation, and a small mine was observed in operation in Sec. 22 of the Ninemile area. Shale for use in the manufacture of cement, sand, gravel and quartz conglomerate are available for future use.

In various localities, aragonite, Mexican onyx, tufa, and quartz crystals have been found. Their main use is for decoration or mineral collections.

In Sevier Valley salt, gypsum, and bentonite are still mined for commercial purposes. The bentonite is used for lining irrigation ditches, in stock ponds or reservoirs to control leakage, as covering for roofs, and filler for soap. Its valuable property is swelling to $3\frac{1}{2}$ times its size after grinding and addition of water. Formerly, calcite of optical quality was mined from near Salina Canyon, in Sevier Valley.

Metallic mineral prospects in Sanpete County have been generally unproductive. Very few mines have been profitable. One of these, the Santobar Mine in the foothills of the Gunnison Plateau northwest of Ephraim produced, in 1967, 4,200 dollars worth of lead, zinc, and silver ore from the Flagstaff Limestone near its contact with the North Horn Formation. Samples from Cedar Hills, and from the upper Sixmile Canyon have been assayed for manganese, but these areas have never been mined.

Local prospectors often report mining small veins, but they are usually disenchanted when the vein is lost in a fault zone or becomes unproductive.

Pratt and Callaghan (1970, p. 53) explain the lack of ore deposits as the result of sedimentary formations,which have not been intruded by granitic intrusive rocks, or covered by lavas. However, the numerous fault zones could have served as avenues for ascending hydrothermal solutions, thus mineralizing the faults or replacing the limestone formations with ore deposits. One can surmise that ore deposits in the region may have been lost because of erosion, or lie in fault zones covered by valley alluvium. Judging from the known occurrences of mineralized areas, such as the Santobar Mine and the now barren lead-zinc mine in Salina Canyon, it is anomalous that mineralization could have occurred on such a small scale considering the magnitude of some of the faults in the area.

Coal was discovered in San Pete Valley in 1869. It was being commercially mined for the Salt Lake City market in 1870. The coal producing formation was the North Horn. In 1887, coal was being produced from the Sixmile Canyon Formation near Sterling, but production ceased when the mine waters became too costly to drain. By the early 1940's coal production had ceased in the valley.

In 1956, the Joe's Valley gas field was discovered in the eastern part of San Pete County. The gas was obtained from the Ferron Sandstone and the Dakota Formation. Later, test drilling near Moroni indicated that the Ferron Sandstone and Dakota persisted at least into that area. However, only a show of gas was obtained and no petroleum. Other wells have been drilled in scattered locations in Sanpete and Sevier Counties without much success.

But in the summer of 1970, according to the financial pages of the Salt Lake City Tribune, some of the major oil companies began buying oil and gas leases in Sanpete County. And on our final excursion into Dry Canyon with the field group, we observed a seismic crew collecting geophysical data. Thus, there is renewed interest in the prospects for oil and gas in the area.

GEOMORPHOLOGY

The outstanding geomorphic features of the area are structural in origin. These include the Wasatch Plateau, which embodies the Wasatch monocline, the Gunnison Plateau (San Pitch Mountains), the San Pete and Sevier Valleys, the Redmond, Arapien, and Cedar Hills, the Valley and Wasatch Mountains, and numerous cuestas and hogbacks in both the San Pete and Sevier Valleys. These features typify the transition zone between the Colorado Plateau Province and the Basin and Range Province.

The entire drainage area of the San Pitch River, a major tributary of the Sevier River, and a portion of the Sevier River are included in Sanpete County. The Sevier River flows into Sevier Lake in west-central Utah. Numerous permanent and intermittent streams flow into the San Pitch and Sevier Rivers from the Wasatch Plateau, and intermittent stream courses enter the valleys from the Cedar Hills, Gunnison Plateau, and Valley Mountains. The basic stream drainage pattern is dendritic, but trellis drainage predominates in the areas where cuestas and hogbacks are present.

Glacial and peri-glacial landforms are present on the Wasatch Plateau. Glacial cirques and moraines are found near Manti. Mass movement resembling solifluction is found on the North Horn Formation of the upper Wasatch Plateau.

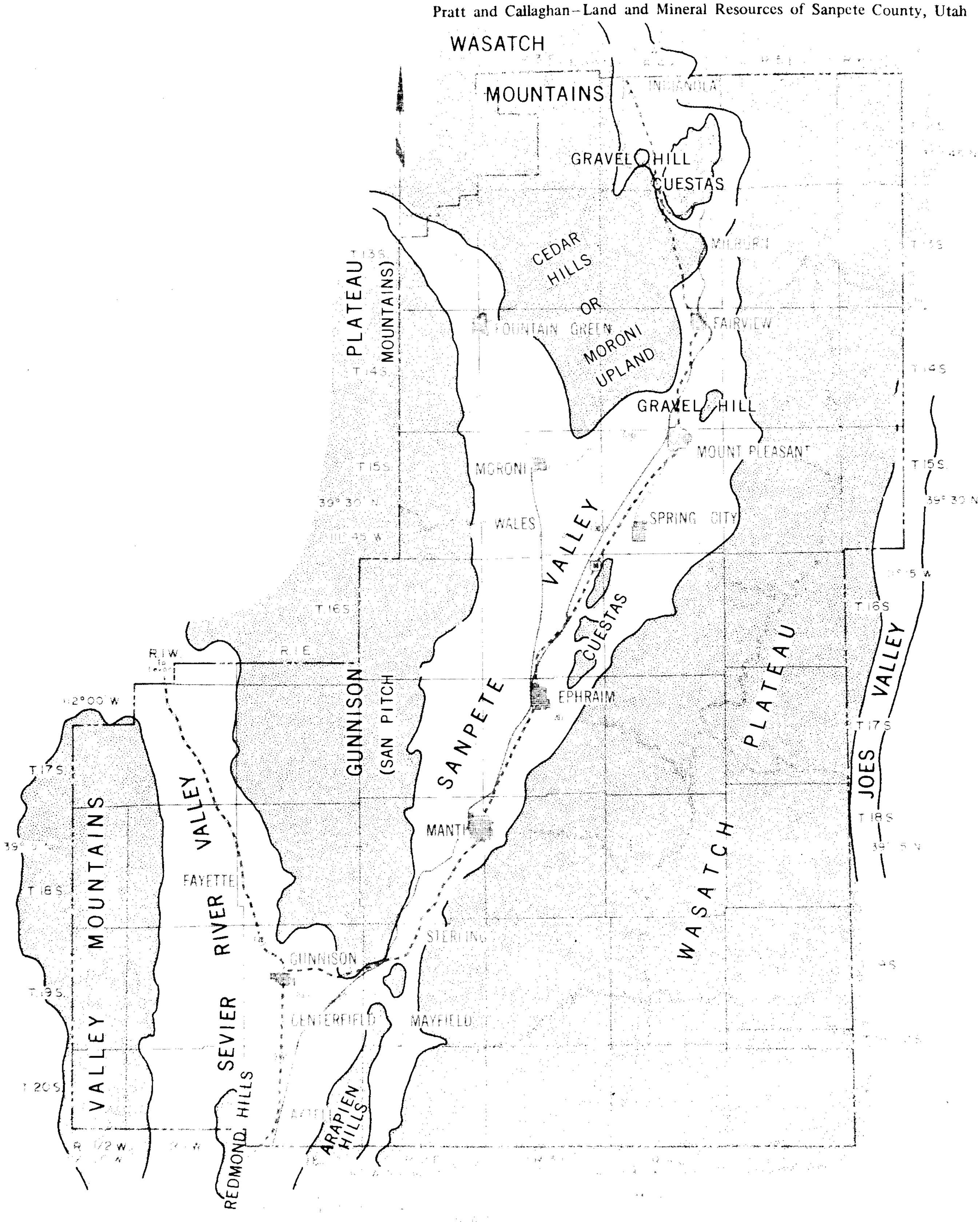

Fig. 2.

Geomorphic Regions

Other forms of mass movement found in the North Horn Formation of the upper Wasatch Plateau are debris avalanches, debris flows, and protalus ramparts. Numerous landslides involving the Crazy Hollow, Green River, Colton, and Flagstaff Formations are found along the Wasatch front between Manti and Ephraim.

In the Snows Canyon Area, a large scarp is present in the Green River Formation with a toreva block below it. Beneath the block is landslide debris from the Flagstaff, Colton, and Green River Formations. (Green, 1969, p. 27) In the Ninemile Area, a large quantity of colluvium and what appears to be a small landslide are found in section 6 of the map area.

There are striking examples of chemical and mechanical weathering in the area. The chemical breakdown of salt and gypsum in the Arapien Shale accelerate the erosion of this formation. Although chemical weathering is evident in the more competent Flagstaff and Green River Formations, frost-wedging could also be seen on the chemically resistant ledges of these formations.

Soils of the region are generally shallow. They are basically lithosols, rough stony land, or gray-brown desert soils. Soils differ greatly in short distances according to the parent material of the bedrock.

The soils below an altitude of 8,000 feet are of the pedocal type (characterized by a limy sub-soil). In the area near Sterling, caliche has developed on the soil.

Above 8,000 feet pedalfers (Al, Fe, or non-limy soils) are developed. This type may include the more fertile gray-brown podzolic soils. In the valleys and along the flood plains of the rivers rich, alluvial soils have developed. (Hunt, 1956, pp. 6-7)

GEOLOGIC HISTORY[2]

The geologic history of the exposed rocks of the area began with the deposition of the Arapien Shale during the Middle and Late Jurassic. It was deposited on older Mesozoic and Paleozoic rocks, and these deposits assumed the form of a geosyncline trending about north and south.

The Arapien Shale was deposited in a complex environment, which included an initial invasion of the Jurassic Sea, that deposited mudstones, siltstones, and shales, followed by a regression of the sea producing a closed basin environment necessary for the deposition of rock salt and gypsum. Later, after more mudstones were deposited, closed basins again prevailed forming rock salt deposits. After the deposition of the Arapien Shale there was a re-invasion of the Jurassic Sea, which deposited the mudstones, siltstones, and sandstones of the Twist Gulch Formation.

In Upper Jurassic, and possibly Early Cretaceous times the Morrison (?) Formation was deposited in a flood-plain environment, although cross-bedded sandstones also indicate the presence of deltaic deposits.

Penecontemporaneous with the deposition of the Morrison (?) Formation was an initial orogenic uplift to the west, which produced the highlands that were the source of the Morrison (?) Formation in central Utah.

There are no specific Lower Cretaceous formations in the area,

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[2]Modified after Spieker, 1946, pp. 156-160 and Spieker, 1949, pp. 77-81.

possibly because of a uniform erosion interval, but more likely because of non-deposition. The evidence for this is that there is no precise boundary in many places, and no angular unconformity between the Upper Cretaceous Indianola Group and the Morrison (?) Formation.

During the Late Cretaceous (early-late Colorado) the Indianola Group was deposited. It is composed of the following formations:

a) The San Pete Formation, which consists of sandstone, conglomerate and some shale, is of early Colorado age. It is mostly marine, but near the top there are continental (fluvial) beds.

b) The Allen Valley Shale consists mostly of marine shale with beds of bentonite, siltstone, and sandstone. It is also of early Colorado (Carlisle) age.

c) The Funk Valley Formation, which is composed of marine sandstone and shale and is of medial Colorado (Niobrara) age.

d) The Sixmile Canyon Formation was deposited in a fluvial, lagoonal, and swamp environment. A prominent coal member is present along with a sandstone conglomerate, and conglomeratic sandstone beds. It is of late Colorado age.

During the deposition of the Indianola Group there were two episodes of orogenic uplift. The evidence for these orogenies is the conglomerate facies in the San Pete and Sixmile Canyon Formations. Moreover, their position and an increase in thickness westward indicate that the source areas were highlands to the west.

Following the deposition of the Indianola Group, during the Upper Cretaceous, in medial and late Montana time, the early Laramide orogeny occurred. The evidence for the early Laramide orogeny is the regional angular unconformity between the Indianola Group and the Price River Formation, the prominent Castlegate Sandstone tongue in the lower Price River Formation of east-central Utah, and the existence of major folds, such as the San Pete-Sevier Valley anticline.

Also in late Montana time, during the Laramide orogeny the Price River Formation was deposited. The source area was mainly the late Cretaceous Wasatch Mountains, although some of the conglomerates are erosional material from the anticline.

During late Cretaceous (Lance) and Early Paleocene time the North Horn Formation was deposited. The source of the lower North Horn Formation conglomerates is further erosion of the anticline. However, the high energy environment and rapid erosion also resulted in later damming of streams, thus the upper North Horn is predominantly composed of lacustrine limestones and mudstones.

The earliest known normal faulting occurred in the Paleocene during the deposition of the North Horn Formation. The evidence for this is the graben in Dry Canyon. However, in its early history the graben was a horst, but there was a reversal of movement along the faults resulting in the graben later in time.

After this event, there occurred the Early Paleocene pre-Flagstaff monoclinal arching. This crustal movement involved the Price River and North Horn Formations and resulted in a monocline with the tilted limb dipping eastward. The underlying formations of the Indianola Group were only affected by a slight change in dip by this movement. This event can be clearly seen in the Sixmile District.

Following the monoclinal folding, the Flagstaff Limestone was deposited in the Paleocene and early Eocene in a lacustrine environment, although locally fluvial sandstones prograde into the lake. The Flagstaff Limestone was deposited unconformably on the North Horn Formation in the Sixmile District.

In the Early Eocene, the Colton Formation was deposited in a complex environment. It consists of rocks of floodplain, channel, deltaic, and lacustrine origin. These rocks are characteristically green and brown mudstones, siltstones, micaceous sandstones, gray and red shale, and some limestone.

In early or medial Eocene time, post-Colton, pre-Green River normal faulting occurred on the west slope of the Gunnison Plateau. The evidence for this is that the Flagstaff Limestone is in angular contact with the Arapien Shale faulted against the Green River Formation, which is also in angular unconformity over the Arapien Shale. The position of the Colton Formation between the Flagstaff Limestone and Green River Formation indicates the faulting is post-Colton.

Later, in medial Eocene time, the Green River Formation was deposited in a lacustrine environment, but deltaic and fluvial facies are present in other areas. The Green River Formation has a complex lithology, however in central Utah it is characterized by gray and tan limestones, oolitic limestone, gray and green shale, green and brown mudstone, some siltstone, and conglomerate, and numerous interbedded tuffs.

Following the deposition of the Green River Formation there was a sequence of normal faulting in the Salina District. Then in the late Eocene the Crazy Hollow Formation was deposited in a fluvial environment. It is generally composed of micaceous sandstone, conglomerate, red mudstone, and reworked volcanics.

Beginning in the late Eocene and ending in the Miocene was the flexing and faulting of the Wasatch monocline. This event was caused by subsidence of the San Pete-Sevier Valley block and the regional uplift of the Wasatch Plateau area. Tension caused by the uplift resulted in the grabens of the upper monocline and the antithetic faults of the monocline front.

Later in the Eocene and Miocene, there was thrust faulting of the Flagstaff, Colton, Green River, and Crazy Hollow Formations along the angular unconformity with the Arapien Shale. This feature may be observed in the lower San Pete Valley and in the Salina District.

In the late Eocene (?) or early Oligocene (?) the Bald Knoll Formation was deposited over the Crazy Hollow. This formation consists of white to light-gray siltstone and is found southwest of Salina. In the Oligocene (?), the Gray Gulch Formation, consisting mainly of pyroclastics, was deposited disconformably over the Crazy Hollow Formation in parts of the Salina district. This formation is similar and probably contemporaneous with the Moroni Formation of Cedar Hills and the Bullion Canyon Formation of south-central Utah.

Beginning in the Miocene and ending in the Oligocene was a sequence of normal faulting caused by tensional forces resulting in the Gunnison Fault.

Also in the Miocene there was a thrust faulting of the pyroclastics of the Gray Gulch Formation near the mouth of Twist Gulch.

Following this episode of thrusting, lava beds were extruded in the vicinity of Salina. These are part of the great lava fields of the central High Plateaus in Utah. Since the lavas are strongly tilted, this indicates a time of post-volcanic thrusting in the late Tertiary.

After the volcanics, the Axtell Formation was deposited in the area. It is of late Tertiary and Quaternary age, and is composed of fragments of all other bedrock in the area.

In the southern part of San Pete Valley and in the Sevier Valley the Axtell Formation is often tilted in a manner that indicates an interval of minor folding.

During the Pleistocene and in Recent time evidence indicates movement along the normal faults. This evidence includes the presence of scarplets in the alluvium along the Gunnison front, faults in glacial cirques east of Manti, and rifts of recent origin in the southern High Plateaus. In modern times also, earthquakes have been recorded in the San Pete Valley with a magnitude of up to 4.5 on the Richter Scale. (Pratt and Callaghan, 1970, p. 18)

Finally, erosion of the present surface is evident by the continual flow of alluvium into the San Pete and Sevier valleys.

REFERENCES CITED

Babisak, J.B., 1949, The geology of the southeastern portion of the Gunnison Plateau: unpublished M.S. thesis, The Ohio State University.

Bagley, J.M., 1964, Water yields in Utah: Special Report 18, Utah Agr. Expt. Sta., Utah State Univ., with Utah Water and Power Board.

Baker, A.A., Dane, C.H., and Reeside, Jr., J.B., 1936, Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U.S. Geol. Survey Prof. Paper 183.

Baker, A.A., 1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U.S. Geol. Survey Oil and Gas Investigations Prelim. Chart No. 30.

Berry, E.W., 1925, Flora and ecology of so-called Bridger beds of Wind River Basin, Wyoming: Pan-Am. Geologist, vol. 44, p. 360.

Billings, M.P., 1933, Thrusting younger rocks over older: Am. Jour. Sci., 5th ser., vol. 25, pp. 140-165.

Bradley, W.H., 1931, Origin and microfossils of the oil shale of the Green River Formation of Colorado and Utah: U.S. Geol. Survey Prof. Paper 168.

Dutton, C.E., 1880, Report on the geology of the High Plateaus of Utah: U.S. Geog. Survey Rocky Mountain Region (Powell Survey), pp. 153-154, 163-165.

Eardley, A.J., 1933, Stratigraphy of the southern Wasatch Mountains, Utah: Michigan Acad. Sci. Papers, vol. 18, pp. 330-334.

Eldridge, G.H., 1894, Description of the sedimentary formations: U.S.

Geol. Survey, Geol. Atlas, Anthracite-Crested Butte Folio, No. 9.

_______________, and Emmons, S.F., 1896, Geology of the Denver Basin in Colorado: U.S. Geol. Survey, Mon. 27.

Gill, J.R., 1950, Flagstaff Limestone of the Spring City-Manti Area, San Pete County, Utah: unpublished M.S. thesis, The Ohio State University.

Gilliland, W.N., 1948, Geology of the Gunnison Quadrangle: unpublished Ph.D. dissertation, The Ohio State University.

_______________, 1963, San Pete-Sevier Valley Anticline of central Utah: Geol. Soc. America Bull.v. 74, pp. 114-123.

Green, P., 1969, Geological report of the Snows Canyon Area, San Pete County, Utah: unpublished senior thesis, The Ohio State University.

Gregory, H.E., 1951, The geology and geography of the Paunsaugunt region, Utah: U.S. Geol. Survey Prof. Paper 226.

Hardy, C.T., 1949, Stratigraphy and structure of the Arapien Shale and Twist Gulch Formation in Sevier Valley: unpublished Ph.D. dissertation, The Ohio State University.

Hayden, F.V., 1869, Preliminary field report (third annual) of the U.S. Geol. Survey of Colorado and New Mexico: Bulletin of the U.S. Geol. and Geogr. Survey of the Territory, p. 90.

Howell, E.E., 1875, Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico examined in the years 1872 and 1873: U.S. Geog. and Geol. Surveys W 100th Mer. Rept., v. 3, pp. 175, 236.

Hunt, C.B., 1956, Cenozoic geology of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 279.

Knowlton, F.H., 1920, A dicotyledonous flora in the type section of the

Morrison Formation: Am. Jour. Sci., 4th ser., vol. 49, pp. 189-194.

La Rocque, A., Tertiary mollusks of central Utah: Geol. and Econ. Deposits of East Central Utah, Seventh Ann. Field Conference, I.A.P.G., pp. 140-146.

Lee, W.T., 1920, Type section of the Morrison Formation: Am. Jour. Sci., 4th ser., vol. 49, pp. 183-188.

Pratt, A.R., and Callaghan, E., 1970, Land and mineral resources of San Pete County, Utah: Utah Geol. and Mineralog. Survey Bull. 85.

Reeside, J.B., Jr., 1931, Supposed marine Jurassic (Sundance) in foothills of Front Range of Colorado: Am. Assoc. Petrol. Geol. Bull., vol. 15, pp. 1095-1103.

Richardson, G.B., 1907, Underground water in San Pete and central Sevier Valleys, Utah: U.S. Geol. Survey Water-Supply Paper 199, pp. 8-9.

Schoff, S.L., 1937, Geology of the Cedar Hills, Utah: unpublished Ph.D. dissertation, The Ohio State University.

Spieker, E.M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geol. Survey Prof. Paper 205-D, pp. 117-161.

____________________, 1949, Transition between the Colorado Plateaus and the Great Basin in central Utah: Utah Geol. Soc., Guide Book No. 4.

____________________, and Reeside, J.B., Jr., 1925, Cretaceous and Tertiary formations of the Wasatch Plateau, Utah: Geol. Soc. America Bull., vol. 36, pp. 435-454.

____________________, and ____________________, 1926, Upper Cretaceous shoreline in Utah: Geol. Soc. America Bull., vol. 37, pp. 429-438.

Stokes, W.L., 1944, Morrison Formation and related deposits in and adjacent to the Colorado Plateau: Geol. Soc. America Bull. vol. 55, pp. 951-992.

Wegemann, C.H., 1913, The Coalville coalfield, Utah: U.S. Geol. Survey Bull. 581, pp. 161-187.

Wood, H.E. 2nd, Chairman and others, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., vol. 52, pp. 1-48.

APPENDIX

STRATIGRAPHIC SECTIONS

OF FORMATIONS IN THE

NINEMILE AREA

STRATIGRAPHIC SECTIONS

STRATIGRAPHIC SECTION NO. 1.

Section across the Arapien Shale (Sec. 18, S.E. $\frac{1}{4}$).

		Thickness Feet
Green River Formation		
Arapien Shale		
1.	Shale, red, interbedded with mudstone, gypsiferous in the lower part.	120
2.	Shale, light gray, interbedded with gray mudstone.	175
3.	Shale, light red, interbedded with red mudstone; selenite flakes promenent.	75
4.	Shale, gray, interbedded with gray mudstone; selenite crystals prominent.	375
5.	Salt bed, shale grades into salt bed, halite crystals present.	10
6.	Shale, gray interbedded with gray-brown mudstone.	75
7.	Sandstone, gray-brown, resistant bed.	20
8.	Mudstone, gray-brown, interbedded with gray shale.	150
9.	Sandstone, yellow-brown, resistant bed.	30
10.	Mudstone, green-brown, mottled with iron stain.	170

		Feet
11.	Mudstone, light red, grading into gray, shaly mudstone; selenite flakes present.	10
12.	Mudstone, gray, grading into light-brown, shaly, mudstone.	375
13.	Covered, by Axtell Formation.	6
14.	Mudstone, gray, with interbedded gray-brown shale.	10
15.	Mudstone, red, interbedded with shaly mudstone; selenite flakes present.	8
16.	Mudstone, gray, interbedded with sandy shale.	7
17.	Mudstone, red, selenite flakes, thin-bedded.	1
18.	Mudstone, light gray, interbedded with gray shale. . . .	26
19.	Mudstone, light green-brown.	6
20.	Sandstone, gray, interbedded with gray, shaly mudstone.	90
21.	Shale, light gray, interbedded with gray-brown sandstone.	35
22.	Shale, light gray, interbedded with mudstone in the upper part, the base of the unit is a gray-brown sandstone bed two feet thick.	130
23.	Sandstone, light gray, interbedded with gray, shaly mudstone, grades into light gray-brown sandstone in the upper part of the unit.	70
24.	Claystone, gray, interbedded with light gray-green, shaly, mudstone, with some iron-staining.	35

Feet

25. Sandstone, light brown, mottled by iron stain, interbedded with shale. 30

Total thickness of the Arapien Shale. 2039

Alluvium

STRATIGRAPHIC SECTION NO. 2.

Section across the Twist Gulch Formation (Sec. 17, N.E. ¼).

Feet

Green River Formation

Twist Gulch Formation

1. Mudstone, red, lower part of the unit contains veins of gypsum (satin spar) in some places, galena is also present in the gypsiferous part of the formation. 70
2. Sandstone, gray-white, sub-angular to sub-rounded, calcareous cement. 5

Total thickness of the Twist Gulch Formation. 75

Alluvium

STRATIGRAPHIC SECTION NO. 3.

Section across the Morrison (?) Formation (Sec. 5, N.W. ¼).

Feet

San Pete Formation

	Feet
Morrison (?) Formation	
1. Sandstone, yellow, fine-grained, moderate sorting, sub-angular, calcareous cement.	15
2. Mudstone, purple-red, interbedded with purple-red, polymictic conglomerate, mainly quartzite pebbles, cobbles, and boulders, lesser amounts of mudstone, limestone and sandstone fragments, calcareous matrix with sandstone grains and quartz and chert pebbles.	480
3. Conglomerate, purple-red, quartzite pebbles, sandy calcareous matrix.	35
4. Sandstone, yellow-brown, calcareous cement.	6
5. Mudstone, light reddish-brown, calcareous.	20
6. Sandstone, light yellow-brown, calcareous cement; sub-angular, moderate sorting, cross-bedding prominent indicating overturned beds. . . .	25
7. Conglomerate, purple-red, quartzite boulders, and sandstone fragments, calcareous matrix.	20
8. Mudstone, orange-red.	25
9. Sandstone, pale purple-red, with interbedded purple-red conglomerate; sandstone is poorly sorted.	30
10. Mudstone, orange-red, interbedded with polymictic conglomerate and orange-red sandstone.	60
11. Sandstone, yellow-brown, interbedded with	

		Feet
	conglomerate.	20
12.	Mudstone, orange-red, interbedded with conglomerate.	75
13.	Conglomerate, purple-red, numerous quartzite boulders, lesser amounts of limestone, mudstone and sandstone fragments, quartz pebbles present, calcareous matrix.	40
14.	Mudstone, orange-red, with a conglomerate lens. . .	35
15.	Conglomerate, purple-red, polymictic, mainly quartzite boulders, some limestone and sandstone fragments, calcareous matrix.	40
16.	Mudstone, orange-red, interbedded with yellow-brown sandstone, in the upper part of the unit, the sandstone may grade into a pebbly conglomerate.	45
17.	Conglomerate, purplish-red, prominent bed, numerous quartzite and limestone boulders, some mudstone boulders and sandstone fragments, quartz and chert pebbles present, sandstone matrix cemented with calcium carbonate.	35
18.	Mudstone, purple or reddish purple, calcareous cement.	80
19.	Conglomeratte, polymictic, contains large boulders of cemented sandstone and	

Feet

mudstone, along with limestone, quartz, and chert pebbles, sandstone matrix. 75

20. Mudstone, orange-red, interbedded with sandstone. 175

21. Mudstone, purple-red, interbedded with pebbly nodular limestone. 200

22. Conglomerate, gray, polymictic, quartz and chert pebbles along with calcareous mudstone pebbles; matrix composed of sandstone cemented with calcium carbonate. 35

23. Mudstone, red, interbedded with limestone, algal nodules (oncolites) present in the limestone. 50

24. Limestone, gray-white, massive, recrystallized, jointed, quartz and jasper pebbles present along with oncolites. 40

Total thickness of the Morrison Formation. . .1671

Alluvium

STRATIGRAPHIC SECTION NO. 4

Section across the San Pete Formation (Sec. 6, N.E. $\frac{1}{4}$).

Feet

North Horn Formation

San Pete Formation

1. Sandstone, yellow-brown, sub-angular

		Feet
	calcite cement.	30
2.	Sandstone, brown, angular to sub-angular, calcite cement, interbedded with gray-brown shale.	35
3.	Conglomerate, gray-brown, mainly sandstone and limestone clasts, calcareous matrix with sand grains and quartz pebbles, interbedded with brown sandstone.	40
4.	Sandstone, brown, sub-angular, calcite cement, interbedded with gray-brown shale.	30
5.	Sandstone, yellow-brown, angular to sub-angular, silica cement.	15
6.	Conglomerate, gray-brown, mainly sandstone clasts, calcareous matrix with sandstone grains and quartz pebbles, interbedded with minor amounts of sandstone.	8
7.	Sandstone, light brown, sub-angular, calcite cement, interbedded with shale.	20
8.	Sandstone, gray-brown, sub-angular to sub-rounded, calcite cement.	35
9.	Covered, center of amphitheater is covered with a fairly thick layer of colluvium and alluvium.	175
10.	Sandstone, yellow-brown, sub-angular, clay cement. .	15
11.	Conglomerate, gray-brown, sandstone and limestone	

Feet

clasts, matrix of calcium carbonate with some sand grains and quartz pebbles. 18

12. Sandstone, yellow-brown, sub-angular, calcite cement. 15

13. Shale, gray-brown interbedded with minor amounts of sandstone. 25

14. Sandstone, light brown, sub-angular, medium-grained, silica cement. 12

15. Sandstone, light yellow-brown, medium-grained sub-angular, interbedded with light brown shale. . . 95

16. Sandstone, yellow-brown, coarse-grained, angular to sub-angular, silica cement. 15

17. Sandstone, light brown, medium-grained, calcium carbonate cement, interbedded with shale. . 80

18. Sandstone, yellow-brown, medium-grained, silica cement, interbedded with light brown, shaly sandstone. 50

Total thickness of the San Pete Formation. 713

Morrison Formation

STRATIGRAPHIC SECTION NO. 5.

Section across the North Horn Formation (Sec. 6, N.W. $\frac{1}{4}$).

Feet

Flagstaff Limestone

		Feet
North Horn Formation		
1.	Conglomerate, dark gray, clasts composed of large oncolites.	15
2.	Mudstone, red, interbedded with some shale.	110
3.	Sandstone, yellow-brown, fine-grained, sub-rounded to rounded, calcite cement, cross-bedded.	7
4.	Mudstone, red brown, calcareous.	48
5.	Sandstone, light-brown, medium-grained, sub-angular, marly cement.	5
6.	Conglomerate, dark gray, polymictic, chiefly quartz and limestone clasts, marly matrix.	6
7.	Mudstone, red-brown.	35
8.	Sandstone, light yellow-brown, fine-grained, sub-angular to sub-rounded, calcite cement, prominent cross-bedding.	5
9.	Sandstone, yellow-brown, medium to fine-grained, sub-angular, calcareous cement, interbedded with light brown shale.	9
10.	Sandstone, light-brown, medium-grained, sub-angular, calcite cement.	8
11.	Mudstone, yellow-brown, interbedded with light brown shale.	38
12.	Conglomerate, gray-brown, sandstone clasts	

Feet

along with some limestone and quartzite, marly matrix, interbedded with small amounts of sandstone. The conglomerates of the North Horn Formation are mainly channel deposits. 5

13. Sandstone, brown, medium-grained, sub-angular to sub-rounded, calcite cement, prominent cross-bedding indicating beds are not overturned. 8

14. Conglomerate, gray-brown, numerous sandstone clasts with a few of limestone, marly matrix, interbedded with sandstone. 6

15. Sandstone, yellow-brown, angular, coarse-grained, calcite cement. 10

16. Conglomerate, gray-brown, mainly quartzite clasts, a few limestone and sandstone clasts, calcareous matrix. 5

17. Sandstone, gray, medium-grained, sub-angular, calcite cement. 5

18. Conglomerate, gray-brown, quartz sandstone clasts, some chert clasts, calcite matrix. 7

19. Sandstone, yellow, iron-stained, sub-angular to sub-rounded, quartz sandstone in calcite cement. 35

20. Sandstone, yellow, sub-angular to sub-rounded,

Feet

quartz grains in calcite cement matrix. 18

Total thickness of the North Horn Formation 385

San Pete Formation

STRATIGRAPHIC SECTION NO. 6.

Section across the Flagstaff Limestone (Sec. 31, S.E. $\frac{1}{4}$).

Feet

Crest of hill near the radio tower (Sec. 31, S.E. $\frac{1}{4}$).

Flagstaff Limestone

1. Limestone, light gray, recrystallized, silicified, vertical, and bedding joints prominent, honeycomb weathering. 215
2. Mudstone, gray, calcareous. 30
3. Limestone, gray, honeycomb weathering, jointed, silicified. 15
4. Mudstone, gray-brown, calcareous. 70
5. Limestone, gray, honeycomb weathering, jointed, silicified. 15
6. Mudstone, light gray-brown, calcareous, interbedded with some shale, ... 80
7. Limestone, gray, resistant bed, jointed,silicified. .20
8. Mudstone, gray-brown, interbedded with some gray shale. 120

Total thickness of the Flagstaff Limestone. . 565

North Horn Formation

STRATIGRAPHIC SECTION NO. 7.

Section across the Colton Formation (Sec. 17, N.E. $\frac{1}{4}$).

		Feet
Green River Formation		
Colton Formation		
1.	**Mudstone, green, calcareous**	35
2.	Limestone, gray-white, massive, recrystallized. . .	12
3.	Mudstone, green, calcareous.	15
4.	Limestone, gray-white, marly.	10
5.	Mudstone, green, calcareous, interbedded with shale.	30
6.	Limestone, gray-white, marly.	7
7.	Mudstone, green, calcareous, interbedded with shale.	35
8.	Limestone, gray-white, marly.	8
9.	Mudstone, green, calcareous.	15
10.	Mudstone, brown, calcareous.	5
11.	Mudstone, green, interbedded with some shale. . . .	10
12.	Mudstone, brown, calcareous, grades into green mudstone.	15
13.	Sandstone, gray, medium-grained, angular-sub-angular, muscovite flakes present.	5
14.	Limestone, gray-white, clay content high (marly). . .	7
15.	Mudstone, light brown, calcareous, interbedded	

		Feet
	with shale.	35
16.	Mudstone, red, calcareous.	40
	Total thickness for the Colton Formation	284

Twist Gulch Formation

STRATIGRAPHIC SECTION NO. 8.

Section across the Green River Formation (Sec. 23, N.W. $\frac{1}{4}$).

Crest of cliff on west side of North Hollow

Green River Formation

		Feet
1.	Mudstone, brown, calcareous, interbedded with shale	50
2.	Mudstone, green and green-brown, gradational with the brown mudstone, calcareous, interbedded with green-brown shale, a tuff bed one foot thick is present in the lower part.	35
3.	Limestone, gray-white, massive, stromatolites present.	115
4.	Claystone, gray-white, non-calcareous.	78
5.	Limestone, tan, oolitic, key bed	4
6.	Claystone, gray-white non-calcareous.	76
7.	Mudstone, green, calcareous.	70
8.	Mudstone, green-brown, calcareous, interbedded with gray-brown, medium-grained, micaceous	

		Feet
	sandstone.	45
9.	Mudstone, brown, calcareous.	29
10.	Mudstone, light green, interbedded with fine-grained, sub-rounded, calcareous cemented, quartz sandstone.	20
11.	Mudstone, green-brown, calcareous, interbedded with a gray-red tuff bed one foot thick.	45
12.	Sandstone, gray-brown, medium-grained, sub-angular, calcareous cement, interbedded with green-brown mudstone.	7
13.	Mudstone, light-green, calcareous.	14
14.	Sandstone, gray-brown, fine-grained, sub-angular to sub-rounded, marly cement, inter-bedded with gray-white claystone.	7
15.	Mudstone, green, calcareous, interbedded with a light red tuff bed 18 inches thick.	30
	Total thickness of the Green River Formation	625

Colton Formation

STRATIGRAPHIC SECTION NO. 9.

Section across the Crazy Hollow Formation (Sec. 22, N.W. $\frac{1}{4}$). Crest of hill near jeep trail (Sec. 22, N.W. $\frac{1}{4}$).

Crazy Hollow Formation

1. Sandstone, red, quartz grains, volcanic

Feet

shards, medium-grained, sub-rounded, well sorted, calcite cement, cross-bedded. 24

2. Sandstone, gray-white, quartz grains, sub-rounded, well sorted, calcite cement, cross-bedded. 25

3. Mudstone, red, calcareous. 6

4. Conglomerate, dark gray, quartzite clasts, jasper pebbles, poor sorting, calcareous matrix with sandstone grains. 20

5. Sandstone, dark gray-white, micaceous grains, volcanic shards, well-sorted, medium-grained, sub-rounded to rounded grains, calcium carbonate cement. 5

Total thickness of the Crazy Hollow Formation. 80

Green River Formation

STRATIGRAPHIC SECTION NO. 10.

Section across the Axtell Formation (Sec. 19, S.E. 1/4).

Crest of hill in Sec. 19, S.E. 1/4.

Axtell Formation

1. Conglomerate, light gray, limestone clasts, poorly indurated with calcite cement, matrix contains sandstone grains and some volcanic shards, moderate sorting. 45

		Feet
2.	Conglomerate, gray-brown, polymictic, limestone and sandstone clastics are dominant, very poor sorting, poorly indurated with marly cement. Matrix contains sandstone grains and volcanic shards.	30
	Total thickness of the Axtell Formation.	75

Green River Formation

STRATIGRAPHIC SECTION NO. 11.

Section of Valley alluvium in Sec. 4, N.E. ¼

Alluvium

1.	Alluvium, older of valley floor.	400
2.	Alluvium, younger, includes alluvial fans, and other deposits near the mouths of canyons; and the most recent deposits along valley streams.	100
	Total thickness of Alluvium.	500

Arapien Shale